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MOVEMENTS OF LAKE TROUT IN TWIN LAKES, COLORADO, IN RELATION TO THE MT. ELBERT PUMPED-STORAGE POWERPLANT

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16. ABSTRACT

Mean movement rates of 34 lake trout (*Salvelinus namaycush*) tagged with ultrasonic transmitters in Twin Lakes, Colorado, ranged from 1.1 m/min in the fall to 1.6 m/min in the summer. Movement rates between 0830 and 1130 were significantly higher than between 2230 and 0500 during spring, summer, and fall. During the fall, afternoon movements were significantly greater than night movements.

Home range sizes of lake trout were larger during the spring, summer, and fall than during the winter. Of the home ranges observed, at least 40% were found in the proximity of the tailrace at all times of the year. More excursions out of home ranges occurred during the spring and fall than during the summer or winter.

Gill netting data indicated that lake trout were more likely to be found near the tailrace during spring and fall than during summer or winter. During the summer, lake trout were found to prefer deep areas of the lower lake. Between July and October, they occupied depths where water temperatures in the lower and upper lakes averaged 10.5 and 8.5 °C, respectively. Few excursions into water warmer than 12 °C occurred. Most lake trout were found within 3 m of the bottom. Movements of fish to within 15 m of shore occurred in all seasons and usually took place between 0600 and 1300. Ripe lake trout were captured at depths ranging from 1.5 to 12 m, but were not captured near the powerplant.

It is likely that the lake trout of Twin Lakes will be least vulnerable to entrainment by pumping operations between 2230 and 0500 and most vulnerable between 0830 and 1130 during spring, summer, and fall. Seasonally, they will be least vulnerable in the winter and most vulnerable in the spring.

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by

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Colorado State University, Fort Collins

July 1980

Applied Sciences Branch
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Denver, Colorado

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On November 6, 1979, the Bureau of Reclamation was renamed the Water and Power Resources Service in the U.S. Department of the Interior. The new name more closely identifies the agency with its principal functions — supplying water and power.

FOREWORD

This report, one of a series resulting from research being done on the ecological effects of constructing and operating the Mt. Elbert Pumped-Storage Powerplant at Twin Lakes, Colorado, is based on a Masters' thesis by Leonard A. Walch in the Department of Fishery and Wildlife Biology at Colorado State University. The work was cosponsored by the Bureau of Reclamation's (now the Water and Power Resources Service) Fryingpan-Arkansas Project, Lower Missouri Region, and Division of Research, Engineering and Research Center.

The ecological studies at Twin Lakes have been divided into pre-operation and post-operation phases. This report includes results of studies performed to find out where and when lake trout move in relation to the pumped-storage powerplant. Plans are to repeat these studies following the commencement of powerplant operation. Results from the two studies will then give us insight into how lake trout react before and after a pumped-storage powerplant is installed. Future projects will benefit from these results, as planners will be able to more carefully consider and weigh the consequences of different designs and operating schedules. This report will also be useful to anyone interested in lake trout from a management standpoint. Data from this report give us some insight as to how lake trout behave in small lakes and reservoirs. What we learn at Twin Lakes can often be applied elsewhere. Twin Lakes is a good lake trout fishery which is supported for the most part by the introduced mysis shrimp (*Mysis relicta*). The addition of a pumped-storage powerplant may alter this food chain. Data such as those presented here give us a better chance at understanding any such changes.

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INTRODUCTION

Pumped storage is a method of electrical power generation that is becoming increasingly popular among energy development entities. Numerous pumped-storage projects have been completed in the past 15 years. Because of the potential impact of these projects there is a great need for both pre-operational and post-operational studies to determine the biological impact of them on aquatic ecosystems. Schoumacher (1976) [72][1] described several ecological studies which have been completed or are presently being conducted at pumped-storage facilities.

Pumped-storage generating facilities operate in a manner similar to regular hydroelectric powerplants; however, one major difference exists. Pumped-storage facilities pump water from a lower storage reservoir to an elevated storage reservoir or forebay during times of low power demand, using excess power in the system. When power demands are peaking, electricity is generated by allowing water from the forebay to flow back to the lower reservoir through the turbines. The pumping process uses 50 percent more power than is produced by the generating process; however, it is an economically sound venture since the dollar value of electricity generated during peak demand times exceeds the cost of energy that is used to pump water uphill during times of low power demand.

Studies have shown that operation of some pumped-storage facilities adversely affect fish populations. Entrainment of fish at pumped-storage facilities has been significant and has often resulted in mortalities during both the pumping and generation cycles (Hauck and Edson 1976; Robbins and Mathur 1976; Serchuk 1976; Boreman 1977 [34, 69, 73, 5]). Entrainment and mortality of fish eggs and larvae have also been reported (Snyder 1975 [79]). Fluctuating water levels associated with pumped-storage powerplant operation have been shown to decrease the reproductive success of some warm water fish (Robbins and Mathur 1976 [69]). Pumped-storage operations can also affect fish indirectly by altering the temperature structure and possibly the productivity of both the upper and lower storage reservoirs (Simmons and Neff 1969; Oliver and Hudson 1976; Simmons 1976 [76, 61, 77]). Changes in these factors can alter spawning times, distribution patterns, and growth of fish.

[1] Numbers in brackets refer to entries in bibliography.

The effects of operating a pumped-storage facility are not always detrimental to fish populations. Some investigators have shown that new fisheries can become established in the upper storage reservoir (Snyder 1975; Robbins and Mathur 1976 [79, 69]). In some situations warm water fish have adjusted nest building to fluctuating water levels (Baran 1971; Bennett 1975 [3, 4]). In addition, some fish are probably not as vulnerable to entrainment as others due to their seasonal or daily movement patterns (Snyder 1975; Serchuk 1976 [79, 73]).

Hauck and Edson (1976) [34] realized the importance of fish movements and their relation to powerplant operation and discussed the need for studies which would show when fish would most likely be moving. They believed entrainment could be minimized by altering pump or turbine operations to correspond to the times when fish were least likely to be moving.

In this study I have addressed the movement and distribution patterns of lake trout (*Salvelinus namaycush)* in relation to the future operation of the Mt. Elbert Pumped-Storage Powerplant, which is located on the northwest corner of lower Twin Lake. The primary goal of the study was to determine if there were any inherent distribution patterns of the lake trout population which would render them more or less vulnerable to entrainment by powerplant operations. Specific objectives included determination of the relative locations and indices of the size of lake trout home ranges during all times of the year, characteristics of daily horizontal or vertical movement patterns which could increase the chances of lake trout entrainment, determination of spawning locations, and movements of spawning lake trout relative to the location of the powerplant.

Description of the Study Area

Twin Lakes is located in the mountains of central Colorado about 24 km south of Leadville, at an elevation of 2802 m. Twin Lakes was originally formed by glacial activity. To date the physical appearance of the lakes has remained relatively unchanged by man except for damming the outlet and dredging the channel connecting the two lakes.

The surface areas at maximum water level are 736.5 ha for the lower lake and 263.4 ha for the upper lake. Depths range to 28 m. The bottom and shoreline topography are shown in figure 1. Lake Creek, the main tributary to Twin Lakes, enters at the western end of the upper lake and drains near the eastern end of the lower lake. Shoreline characteristics and surrounding vegetation have been described elsewhere (Griest 1977 [28]).

The physical and chemical limnology of Twin Lakes has been documented in detail by Sartoris et al. (1977) [71]. In general, Twin Lakes may be described as second class dimictic lakes according to Hutchinson's (1957) [36] classification.

Aquatic vegetation and benthic organisms found in Twin Lakes were described by LaBounty and Sartoris (1976) [44]. The most abundant macroinvertebrates are the introduced opossum shrimp (*Mysis relicta*), three genera of midges (*Chironomus, Phaenopsectra* and *Dicrotendipes*), and fingernail clams (*Pisidium* spp.).

Fish species presently found in Twin Lakes are: rainbow trout (*Salmo gairdneri*), lake trout (*Salvelinus namaycush*), brown trout (*Salmo trutta*), brook trout (*Salvelinus fontinalis*), white sucker (*Catostomus commersoni*), and longnose sucker (*Catostomus catostomus*). An occasional kokanee (*Oncorhynchus nerka kennerlyi*) or cutthroat trout (*Salmo clarki*) may also be found. Introductions of the Atlantic smelt (*Osmerus mordax*) and the Bonneville cisco (*Prosopium gemmiferum*) have been tried but were unsuccessful.

Present Development

In 1962 the Department of Interior was authorized by Public Law 87-590 to begin the Fryingpan-Arkansas Project, which included construction of the Mt. Elbert Pumped-Storage Powerplant and Forebay. It also included plans for a new dam which would increase the area of Twin Lakes by 165 ha (U.S. Bureau of Reclamation 1975 [84]). The powerplant is scheduled to become operational in 1981 and the enlargement dam is scheduled for completion in 1981.

Lake Trout of Twin Lakes

Lake trout were first introduced into Twin Lakes sometime in the late 1800's. The population has thrived and trophy-size lake trout are caught each year. The lake trout reproduce naturally, but for the past several years the Colorado Division of Wildlife has supplemented natural reproduction by stocking fingerling lake trout.

Other researchers have documented the age and growth characteristics and food habits of the lake trout in Twin Lakes (Nolting 1968; Finnell and Bennett 1974; Griest 1977 [59, 19, 28]). Movements and distribution patterns have been studied, but not intensively. A summer distribution pattern characteristic of lake trout in other lakes was observed by Nolting (1968) [59] when he found that lake trout in Twin Lakes

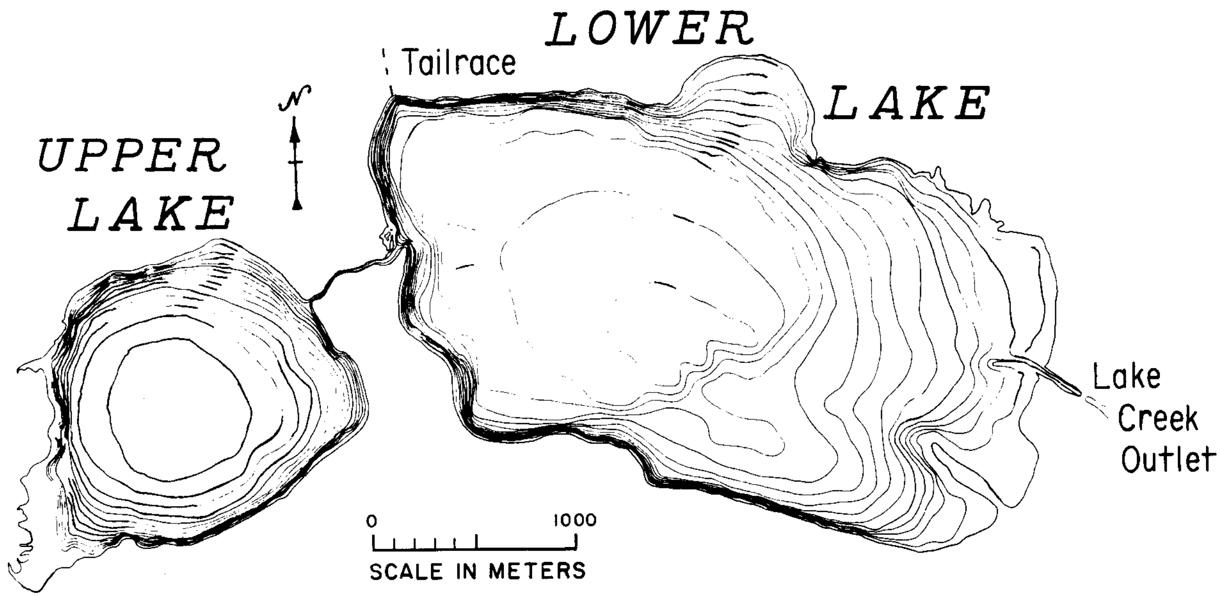

Figure 1.—Bottom contour map of Twin Lakes, Colorado. Elevation of the shoreline contour is 2796.5 m and the contour interval is 1.5 m.

failed to move into shallow water during the summer months. General distribution patterns were studied by Finnell and Bennett (1975) [20] using gill net catch data. They found no significant differences between different areas of the lake when the data were analyzed for within-season and between-season differences. They also found that substantial numbers of lake trout left the lakes via the outlet (Lake Creek) during high water periods in May and June.

Restricted movements of lake trout in Twin Lakes were documented by Finnell and Bennett (1974) [19]. They found that 18 of 22 tagged lake trout were recaptured within 0.5 km of the initial capture and release site.

METHODS

General

Ultrasonic telemetry, gill netting, electrofishing, and trawling techniques were utilized to determine lake trout movement rates, home ranges, and general distribution patterns. All tracking equipment used in this study was manufactured by Smith Root Inc., of Vancouver, Washington. Receiving equipment consisted of a SR-70-H unidirectional hydrophone, a PA-74 preamplifier, a PC-74 pulse counter, and a TA-60 sonic receiver. Several types of Smith Root transmitters (tags) were used. Sizes ranged from 57 mm long, 14 mm in diameter, and weighing 9 g in water, to 120 mm long, 19 mm in diameter, and weighing 40 g in water. To increase the life of the tags, the power output was decreased on most of them. Tags used during 1978, which included seven temperature-sensitive tags, had wire loops attached at each end to facilitate external attachment.

Capture and Tagging of Lake Trout

All lake trout used in the study were captured using gill nets of varying sizes. Gill nets were raised slowly, with frequent pauses, to minimize stress on fish due to temperature and pressure changes. Special care was taken to select for tagging trout which had not been injured in the nets.

During the initial portion of the study transmitters were implanted surgically into the abdominal cavity. The technique used was similar to that used by Summerfelt et al. (1972) [82]. Mortality of surgically tagged lake trout was a problem. Four of 11 surgically tagged lake trout were known to have died at a later date. In addition, the surgical sutures were slow in healing. One lake trout was captured by an angler almost 6 months after tagging, and the sutures were still not completely healed. Thus, an alternative tagging procedure was developed to minimize mortality and stress.

External methods of tagging were examined, and a technique similar to that of Haynes et al. (1978) [35] was used the second field season of the study. During the external tagging process, fish shorter than 550 mm were restrained in a wooden V-shaped holder to prevent excessive movement. Large lake trout could be tagged while they were in large tubs; no restraining mechanisms were necessary, as large fish were very docile and easy to tag. To attach the transmitter to a fish, lengths of 9-kg-test monofilament were tied to the wire loops on the transmitter. The monofilament was then threaded through a small plastic button (15 mm in diameter) and passed through the dorsal musculature of the fish just below the dorsal fin, using a large surgical needle. The monofilament was then passed through another plastic button and a small plastic-coated connector. The transmitter was held firmly against the side of the fish while the connector was crimped.

This external method of attachment was tested in the laboratory using two rainbow trout. The two fish retained the tags for 10 weeks. The activity and feeding behavior of the tagged fish were similar to the control fish after several days. However, there were minor abrasion problems.

One externally tagged lake trout was recaptured 7 months later in a gill net and the transmitter was still attached. The fish appeared to be in good condition. Although some abrasion was apparent, it did not appear serious.

Most externally tagged lake trout were released within 10 minutes following the tagging procedure. Some of the fish tagged internally were held for several hours before release. Tagged trout were either released at the point of capture or were displaced a substantial distance from the capture area to determine if homing to capture locations occurred.

Efforts were taken to keep the weight of transmitters in water from exceeding 2 percent of the tagged fishes' weight out of water. Most authors agree that the 2 percent or less tag-to-fish weight ratio minimizes the effect of the tag on fish stability and buoyancy (Morris 1977; Haynes et al. 1978; Winter 1978 [58, 35, 88]). In the present study the tag-to-fish weight ratio rarely exceeded 2 percent.

Tracking Procedures

The initial tracking schedule during the summer of 1977 consisted of sightings (locations of fish) of tagged trout at least four random times each week. In addition, continuous tracking of each tagged fish for a 2-hour period (three sightings per hour) was conducted four times each week. The 2-hour continuous samples represented one sample from within each 6-hour time period of a 24-hour day (0000-0559, 0600-1159, 1200-1759, and 1800-2359 hours).

The sampling schedule was reevaluated in September 1977 and a new schedule was developed to obtain data on more fish in a given time period. Beginning in September sightings were obtained every 3 hours during a 24-hour sample period. Sightings were obtained on all tagged fish during each 3-hour period. The 24-hour period represented 1 day of each week selected at random. In addition, at least three other random sightings for each fish were taken each week. In the winter and year round on the upper lake, sightings were obtained during daylight hours only. Deviations from the sampling schedule occurred due to weather and lake conditions, equipment malfunctions, and the inability to locate a desired fish during a sampling period.

Movement data were not collected from tagged fish for 2 days following tagging when the external tagging procedure was used and for 6 days when transmitters were internally implanted. These precautions were taken to minimize the chances of recording movements resulting from behavioral changes that could have occurred due to handling or stress from tagging.

During ice-free periods data were collected from an outboard-powered boat. A grid search pattern with listening stops every 300 to 400 m was utilized to locate the ultrasonic signals. Positioning the boat over the tagged fish and determining the position of the boat was accomplished in a manner similar to that used by Dianna et al. (1977) [11]. During the winter the location of tagged lake trout was determined using triangulation techniques described by Poddubnyi et al. (1970) and Dianna et al. (1977) [63, 11].

Trial efforts to locate an activated transmitter placed on the bottom of the lake were conducted in 1977. The boat could be positioned within 10 m of a point directly over the transmitter. Wind and water conditions could reduce the accuracy of boat positioning by an additional 10 m.

Information recorded at each sighting included location, fish identification number, and time of day. In addition, if a lake trout was carrying a temperature-sensitive transmitter, the pulse rate of the tag was recorded. Pulse rates of temperature-sensitive transmitters were dependent on water temperature; thus, the water temperature at the location of the fish was known and the depth of the fish could be determined from temperature profiles of the lake. Bottom depths were also obtained for sightings on fish tagged with temperature tags. These depths were found by sounding with a handline, use of a sonar, or were determined later using the sighting position and contour maps.

Data Analysis

A three-arm protractor was used with sextant sightings to plot fish locations on 1:4800 scale maps. Accuracy of plots was calculated for both ice-free periods and for winter. Accuracy ranged from 0.06 ha during the ice-free seasons to 0.5 ha in the winter.

Calculation of movement rates (meters per minute) was accomplished by a computer program. Movements between sightings were assumed to be straight line movements. Movement rates were not calculated for time periods exceeding 270 minutes. Movement rate data were statistically examined to determine if differential rates occurred on a seasonal or a daily basis. In addition, linear regression analysis was utilized to determine the correlation of several factors with movement rates.

Data plots of individual fish locations were used to develop home range size indices. Home range sizes were calculated several different ways. Once the home range estimates were plotted on maps the areas were measured with a computerized graphics tablet.

Four methods were used to calculate home range size: maximum (Southwood 1966 [80]), cumulative (Odum and Kuenzler 1955 [60]), modified minimum (Harvey and Barbour 1966 [33]), and utilized (Gilmer 1971 [24]). The cumulative and utilized estimates of home range size were used for statistical comparisons of home range size for fish in different seasons. Although the estimates of home range size using the other two methods were not used for comparisons in this study, the values obtained could be of use for comparisons to other studies.

Jennrich and Turner (1969) [37] compared the statistical validity of several methods used to measure home range sizes, and one of their conclusions was that Southwood's (1966) [80] maximum method was a reasonably good method to compare home range sizes, except that it was biased with respect to the number of sightings. Odum and Kuenzler's (1955) [60] cumulative range eliminates most of this bias.

Other aspects of lake trout movements were also studied. Position plots of the lake trout were examined individually with respect to shoreward movements, vertical movements, spawning activities, and homing.

Netting and Electrofishing

Standard netting efforts were conducted at least once each month from January through October 1978 at 10 locations on the upper and lower lakes (fig. 2). Gill nets used were similar to those described by Griest (1977) [28]. Data were examined statistically for seasonal and within-season differences.

Four vertical gill nets were used to obtain information to supplement telemetry data from lake trout tagged with temperature-sensitive tags. All nets were 3 m wide. Depths and mesh sizes ranged from 10 m deep with 6.35-mm bar mesh to 21 m deep with 31.75-mm bar mesh. At least two of the four vertical nets were fished for three 24-hour periods each month from June through October 1978. The locations of vertical net sets are shown on figure 2.

Special netting efforts were conducted during both years of the study to determine lake trout spawning areas and times. During 1977 gill nets were set in the lower lake each week from mid-October until December. Nets were set in suspected spawning areas and near the powerplant. During the month of October and the first week of November 1978, 12 gill nets in the lower lake and 5 in the upper lake were set each week (fig. 3). Small mesh nets were used when possible, to minimize mortality.

Extensive netting using experimental monofilament gill nets (bar mesh ranging from 6.35 to 19 mm) was conducted in 1977 and 1978 in attempts to capture juvenile and young-of-the-year lake trout. Vertical gill netting and otter trawling were also utilized.

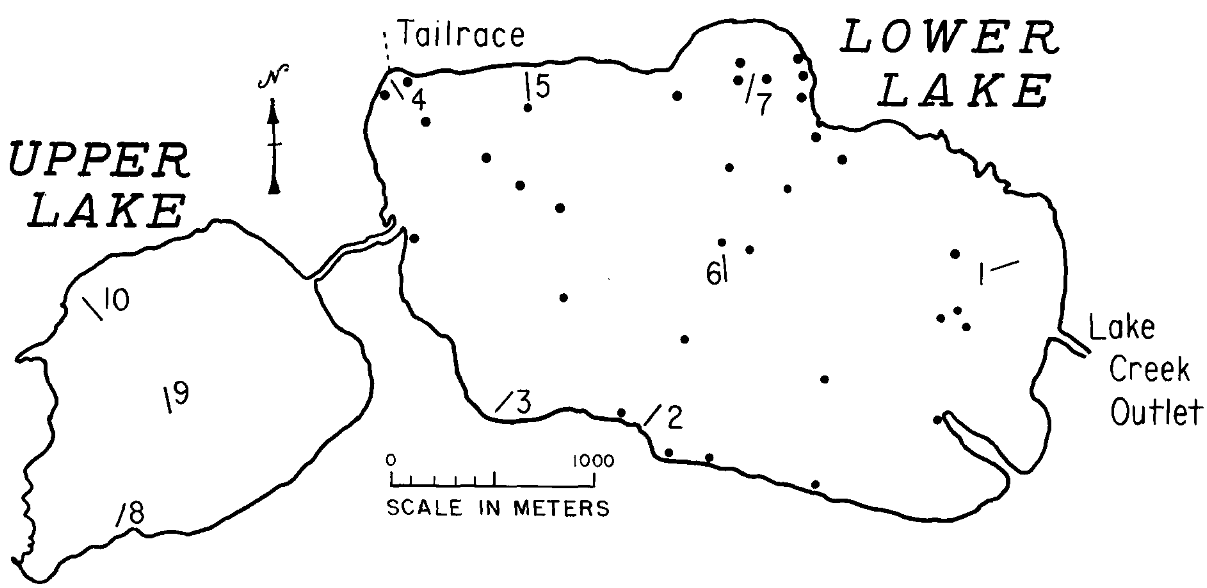

Figure 2.—Locations of standard horizontal and vertical gill net sets in Twin Lakes, Colorado, during 1978. Horizontal sets are numbered 1 through 10. Vertical sets are shown by dots.

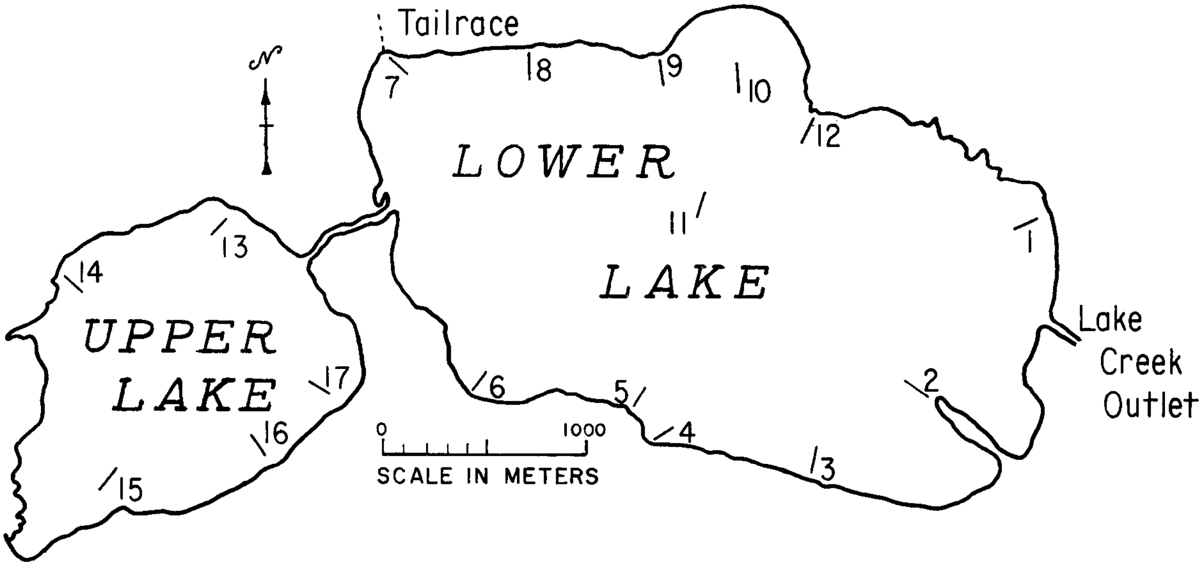

Figure 3.—Locations of weekly gill net sets at Twin Lakes, Colorado, to determine lake trout spawning distributions during October and November 1977 and 1978. Set locations are numbered 1 through 17.

A boat-mounted electrofishing unit was used to gather data concerning the distribution of lake trout in shallow water areas at night. Collections were made in June and August of 1977 and in June, August, and October of 1978. Other electrofishing efforts included shocking of the Lake Creek inflow during October 1978 using a backpack electrofishing unit. This was done to determine if any lake trout were using the area for spawning.

Collection of Limnological Parameters

A Hydrolab Corporation Surveyor Multiparameter Probe was used to record temperature and dissolved oxygen profiles near the center of both lakes at least once every 2 weeks during most of 1977 and 1978. These data were used in the linear regression analysis of fish movement rates to determine if the movement rates were correlated to dissolved oxygen or surface water temperatures.

RESULTS AND DISCUSSION

A total of 34 lake trout (28 in the lower lake and 6 in the upper lake) were tagged between July 1977 and November 1978. Seven of the 34 fish were tagged internally while the remainder were tagged externally. Seven of the 34 were tagged with temperature-sensitive transmitters. Sizes of tagged fish ranged from 405 to 1005 mm in total length. A summary of the tracking information is shown in table 1.

Movement Rates

The calculated movement rates of lake trout were highly variable in all seasons, ranging from 0 to 28 m/min. Average movement rates for all fish from each season ranged from 1.08 to 1.61 m/min (fig. 4). Similar movement rates have been recorded for rainbow trout (Kajihara et al. 1969 [38]), brown trout (Young et al. 1972 [90]; Serchuk 1976 [73]), pike (Poddubnyi et al. 1970 [63]), walleye (Ager 1976 [1]; Kelso 1976 [40]), burbot (Malinin 1971 [49]), carp (Serchuk 1976 [73]), and yellow perch and white suckers (Kelso 1976 [39]).

Examination of individual lake trout movement rates with respect to the time of day indicated that many lake trout were least active at night between 2230 and 0500 and most active during the midmorning hours from 0830 to 1130 (fig. 5). It was also apparent that some lake trout had a lesser activity period around sunset, especially in the winter. Individualistic behavior was apparent for some of the fish. Fish No. 2 was most active at night and fish No. 28 had similar movement rates at all times.

Daily and seasonal trends in activity for the lake trout population were examined by pooling movement rates for all fish from each season.

Table 1.—*Tracking data for 34 lake trout tagged with ultrasonic transmitters between June 1977 and November 1978 in Twin Lakes, Colorado*

Fish No.	Size (mm)	Season tracked	Lake	Number of days tracked	Number of sightings
2	419	summer	lower	12	48
3	534	summer	lower	19	68
4	473	summer	lower	29	92
8	711	summer & fall	lower	34	143
10	800	fall	lower	5	15
11	585	fall	lower	6	20
12	572	fall	lower	4	18
21	473	winter	lower	12	32
23	435	winter	lower	12	32
24	457	winter	lower	12	32
25	700	winter	lower	12	32
26	416	winter	lower	6	14
27	942	spring	lower	13	44
28	425	spring	lower	22	83
29	550	spring	lower	8	33
30	831	spring	lower	10	43
31	670	summer	upper	35	96
32*	405	summer	lower	16	55
33*	415	summer	lower	8	27
34	410	summer	lower	9	23
35*	805	summer	lower	9	37
36	635	summer & fall	lower	38	123
38*	475	summer	upper	18	34
39	820	summer	upper	17	34
41*	425	summer	lower	26	65
42	410	fall	upper	10	16
43	435	fall	lower	19	54
44	410	fall	lower	19	54
45	910	fall	upper	9	12
46*	575	fall	upper	9	14
47*	1005	fall	lower	9	25
48	420	fall	lower	5	14
49	803	fall	lower	5	14
50	840	fall	lower	5	7

*Fish tagged with temperature-sensitive transmitters.

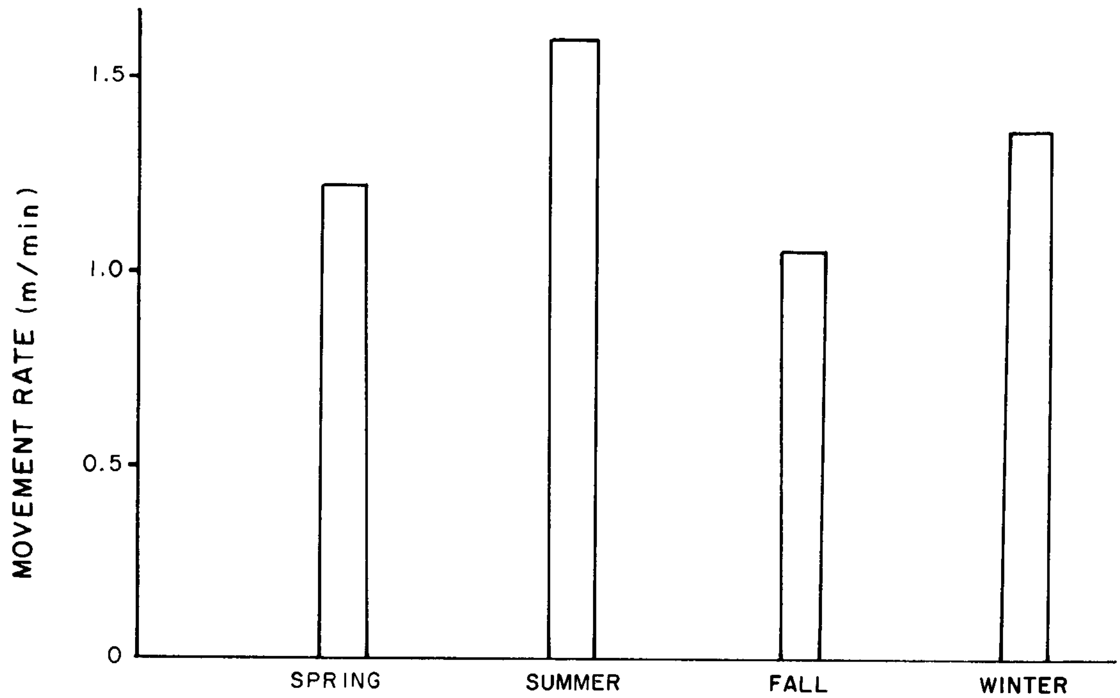

Figure 4.—Mean seasonal movement rates of 34 lake trout from Twin Lakes, Colorado, between July 1977 and November 1978.

Night movement rates were lowest during all seasons, with one exception. During the summer, movement rates were slightly lower between 0500 and 0829 than during the night hours (fig. 6).

A two-way analysis of variance of 944 movement rate observations was used to determine if any statistically significant differences in movement rates occurred. Because no data were collected at night during the winter, two separate analyses were conducted. One analysis included movement rates from all times of the day and night during all seasons except winter. The second analysis included movement rates from all seasons, but only daytime movement rates.

Significant differences (alpha = 0.05) in seasonal and daily activity rates were found in the analysis which included night data (app. A). In the analysis excluding night data, significant differences were found only for daily changes in movement rates (app. B). Homogeneity of variance was lacking among the cells in both analyses (app. C).

Because of the heterogeneity of variance problems, Kruskal-Wallis and Friedman nonparametric analyses of variance by ranks (using mean values of the observations in each cell as a single cell observation) were used to further verify seasonal and daily activity differences. Nonparametric tests have been shown to be more appropriate than the parametric equivalents when homogeneity of variance is lacking (Siegel 1956; Leahman 1975; Elliott 1977 [75, 46,14]).

Using the nonparametric analyses of variance it was found that when winter data were included in the analysis, seasonal and daily changes in the movement rates were not significant (app. D). However, when winter data were excluded and night data included, significant differences (alpha = 0.05) between seasons were observed. The Friedman test for daily differences in movement rates was nearly significant (app. D). Due to the significance of both the parametric and nonparametric analyses, it was felt that statistical comparisons of movement rates between and within spring, summer, and fall were justified.

Multiple mean comparisons in this study were accomplished using the Studentized Range, $Q = \frac{(\bar{X}_{max} - \bar{X}_{min})}{s_{\bar{X}}}$, described by Snedecor and

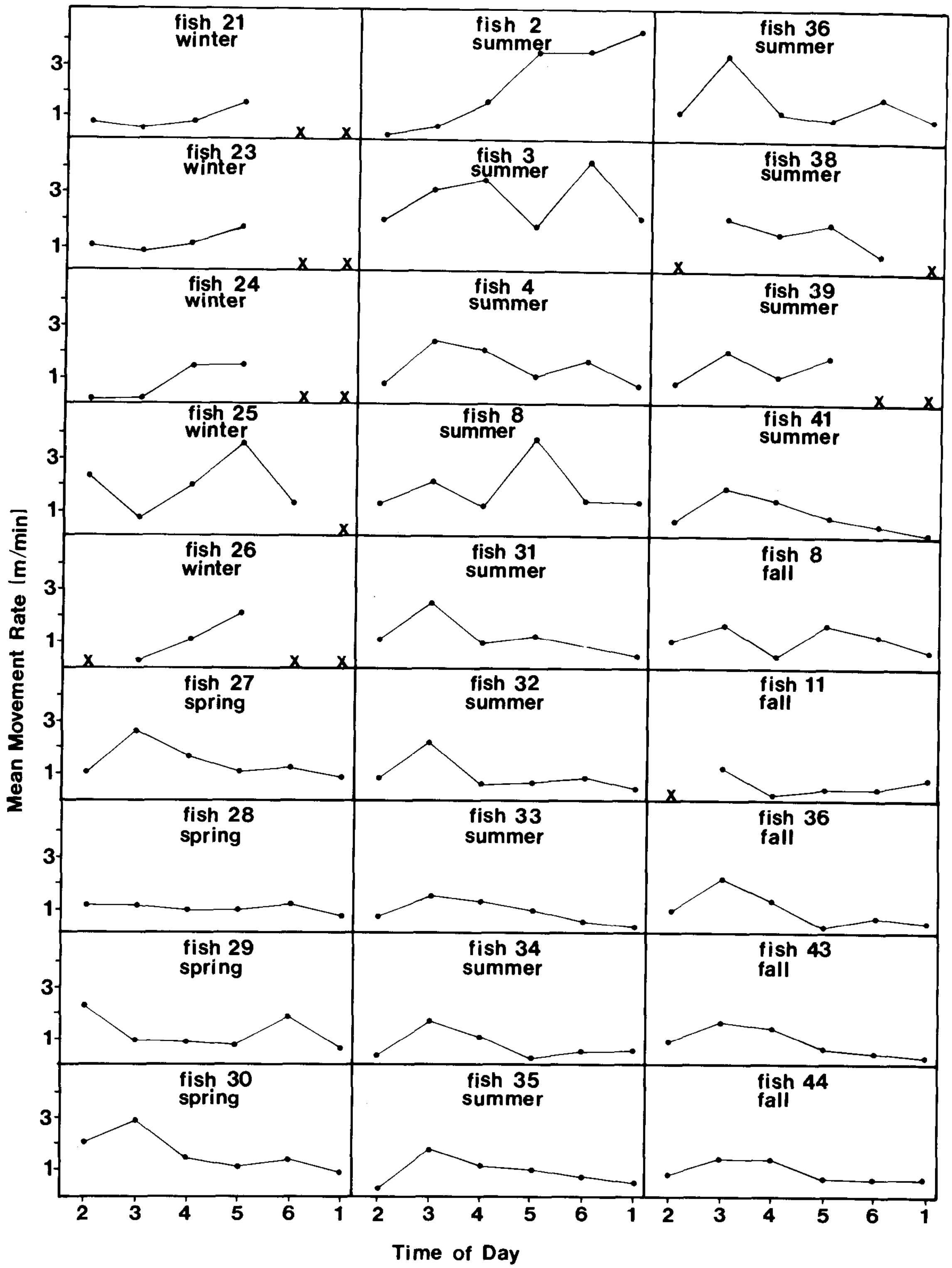

Figure 5.—Mean movement rates for 27 individual lake trout at different times of the day and different seasons of the year in Twin Lakes, Colorado. Time of day is separated into six periods where 1, 2, 3, 4, 5, and 6 represent 2230-0459, 0500-0829, 0830-1129, 1130-1459, 1500-1759, and 1800-2229, respectively. X's represent time periods when no sightings were taken.

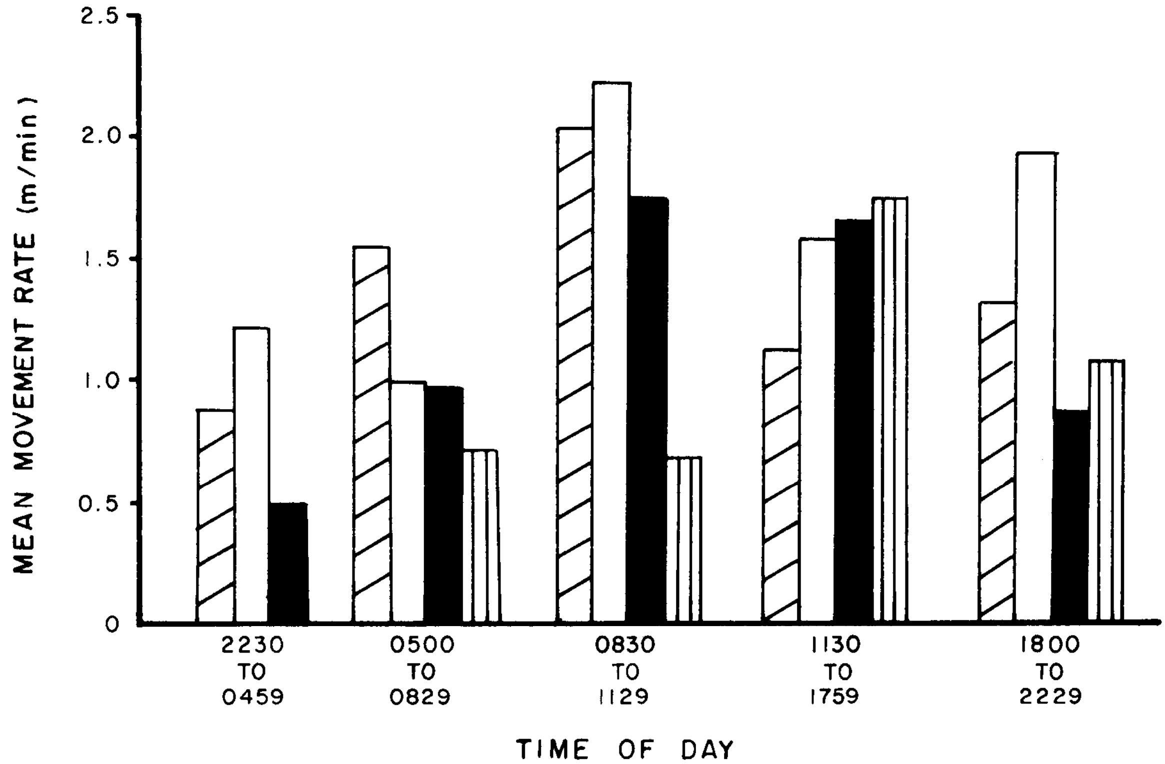

Figure 6.—Mean movement rates of 34 tagged lake trout in Twin Lakes, Colorado, during different seasons of 1977 and 1978 and various times of the day. Diagonal lines represent spring, clear represents summer, solids represent fall, and vertical lines represent winter.

Cochran (1967) [78]. However, the calculation of Q was modified to adjust for the unequal sample sizes encountered in the present study. This was accomplished using the harmonic mean described by Bancroft (1968) [2] to calculate $s_{\bar{x}}$.

When mean movement rates between seasons were compared, the mean seasonal movement rate was significantly higher (alpha = 0.05) in the summer than in the fall. None of the other possible seasonal comparisons were significant. Two comparisons were significant when mean movement rates during the same period of the day but during different seasons of the year were compared. Mean night movements during the fall were significantly lower (alpha = 0.05) than mean night movements during the summer or spring.

Using several one-way analyses of variance, significant differences were found among movement rates from different times of the day during all seasons of the year except winter (app. E). Homogeneity of variance among treatments in each analysis was lacking. Multiple mean tests were used to compare mean movement rates from different periods of the day within the same season despite the heterogeneity of variance problems. It was felt that the multiple mean tests were justified due to the highly significant F values for all seasons except winter (app. E) and the near significance of Friedman's nonparametric test for daily differences in movement rates (app. D).

Within each season except winter, the mean movement rate of lake trout from 0830 to 1130 hours was significantly greater (alpha = 0.05) than the mean movement rate between 2230 and 0500 hours. In addition, the mean movement rate during the late afternoon in the fall was also significantly greater than the mean movement rate between 2230 and 0500 hours. Other comparisons of mean movement rates were not significant. Previous investigators working with other salmonids have found activity patterns similar to those found for lake trout in the present study (Swift 1964; Serchuk 1976 [83, 73]).

Movement rates seemed to be correlated very little to the size of lake trout, surface water temperatures, or the surface dissolved oxygen levels (table 2). Movement rates were somewhat correlated to the duration of the time interval between sightings, but only 13 percent of the variation in movement rates was explained by the time interval factor. Other investigators have had poor success in correlating fish movements to limnological, solunar, or weather parameters (Warden and Lorio 1975; Ager 1976; Maclean 1976; Dudley et al. 1977; McCleave et al. 1977 [86, 1, 48, 13, 54]).

Table 2.—*Linear correlation coefficients and R^2 values of various factors regressed against movement rates of lake trout from Twin Lakes, Colorado, during 1977 and 1978*

Factor	Linear Correlation Coefficient	R^2
Total length of fish	0.091	0.008
Surface dissolved oxygen	-0.061	0.004
Surface water temperature	0.075	0.006
Time interval between sightings	-0.368	0.136

Home Range

Investigators of lake trout home ranges in other localities found that lake trout tended to roam over large areas (Eschmeyer et al. 1952; McCrimmon 1963; Rahrer 1968 [16, 55, 66]). However, even in large lakes, restricted movements of lake trout have been recorded (Fry 1952; Rawson 1961 [21, 67]).

Home ranges were determined for 31 lake trout in upper and lower Twin Lakes using 1404 individual locations of the fish (table 3). The data plots and cumulative and utilized home range areas for each fish are shown in appendix F.

Cumulative home ranges varied in size from 16.36 to 268.22 ha, while utilized home ranges varied in size from 11.38 to 173.00 ha. There were wide variations in home range sizes between fish even within the same season, probably due to individualistic movement patterns. Other investigators have also suggested that a given population may consist of some individuals with wider ranging movements than others (Parker and Hasler 1959; Moody 1960; Stott et al. 1963; Lewis and Flickinger 1967 [62, 57, 81, 47]). Examination of mean seasonal home range sizes indicated that winter home ranges were smaller than home ranges during other seasons (fig. 7).

A one-way analysis of variance was conducted to determine if significant seasonal differences in the size of lake trout home ranges occurred. Two separate analyses were used; one with the cumulative estimates of home range size and one with the utilized estimates of home range size. Because of possible heterogeneity of variance problems, a Kruskal-Wallis one-way analysis by ranks was also conducted. In each test significant differences (alpha = 0.05) in mean home range sizes between seasons occurred (app. D and G).

When seasonal home range sizes were tested using the multiple mean test described earlier, springtime cumulative home ranges were significantly (alpha = 0.05) larger than cumulative home ranges during the winter. Finnell and Bennett (1974) [19] found that recaptures of tagged lake trout in Twin Lakes during the winter were captured closer to the release areas than recaptures during other times of the year. Other investigators have theorized that lake trout have more restricted movements during the winter than during other times of the year (Kennedy 1956; Galligan 1962 [42, 22]). Comparisons between mean utilized ranges were not significant.

An examination of the number of excursions outside the utilized home ranges (fig. 8) indicated that lake trout tended to spend more time outside of these areas during the spring and fall than during the summer or winter. Martin (1951) and Galligan (1962) [50, 22] reported similar findings.

Little relationship could be found between the size of lake trout and the size of their home range (fig. 9). Eschmeyer et al. (1952) [16] found that small lake trout (mean size = 462 mm) covered less area than large lake trout (mean size = 693 mm) in the Great Lakes. Other investigators have also found an increase in the size of home range with an increase in the size

Table 3.—*Estimates of home range sizes of tagged lake trout from Twin Lakes, Colorado, during 1977 and 1978, using four different methods. Home range sizes are given in hectares*

Fish No.	Lake	Season	Maximum Method	Cumulative Method	Modified Minimum	Utilized Method
2	lower	summer	243.83	241.58	83.38	77.24
3	lower	summer	278.77	268.22	236.12	104.45
4	lower	summer	199.55	150.64	145.94	131.13
8	lower	summer	210.24	191.97	145.76	126.73
8	lower	fall	211.21	211.21	49.32	10.15
11	lower	fall	135.33	133.45	**	45.00
21	lower	winter	44.13	44.13	12.51	34.98
23	lower	winter	32.43	32.43	18.71	21.97
24	lower	winter	16.36	16.36	5.75	11.89
25	lower	winter	227.24	181.44	70.21	53.83
26	lower	winter	35.46	35.46	**	11.38
27	lower	spring	166.40	143.80	130.50	97.58
28	lower	spring	172.28	165.33	139.53	98.24
29	lower	spring	265.98	265.98	68.55	17.24
30	lower	spring	257.39	221.03	221.03	57.21
31	upper	summer	133.04	122.33	122.33	122.11
32	lower	summer	100.22	94.25	61.65	72.78
33	lower	summer	135.78	127.33	**	46.45
34	lower	summer	118.48	111.03	**	32.85
35	lower	summer	106.75	94.17	53.83	74.66
36	lower	summer	244.97	215.74	191.03	173.00
36	lower	fall	200.04	195.09	12.43	24.56
38	upper	summer	88.59	85.62	28.22	79.76
39	upper	fall	116.31	96.79	39.65	95.44
41	lower	summer	175.58	122.62	122.62	122.62
42	upper	fall	90.59	90.59	**	**
43	lower	fall	234.56	197.78	141.55	160.82
44	lower	fall	135.97	125.27	84.62	98.91
45	upper	fall	32.72	**	**	**
46	upper	fall	84.02	**	**	**
47	lower	fall	115.50	**	**	**
48	lower	fall	99.34	**	**	**
49	lower	fall	27.59	**	**	**

**Not enough sightings to determine home range.

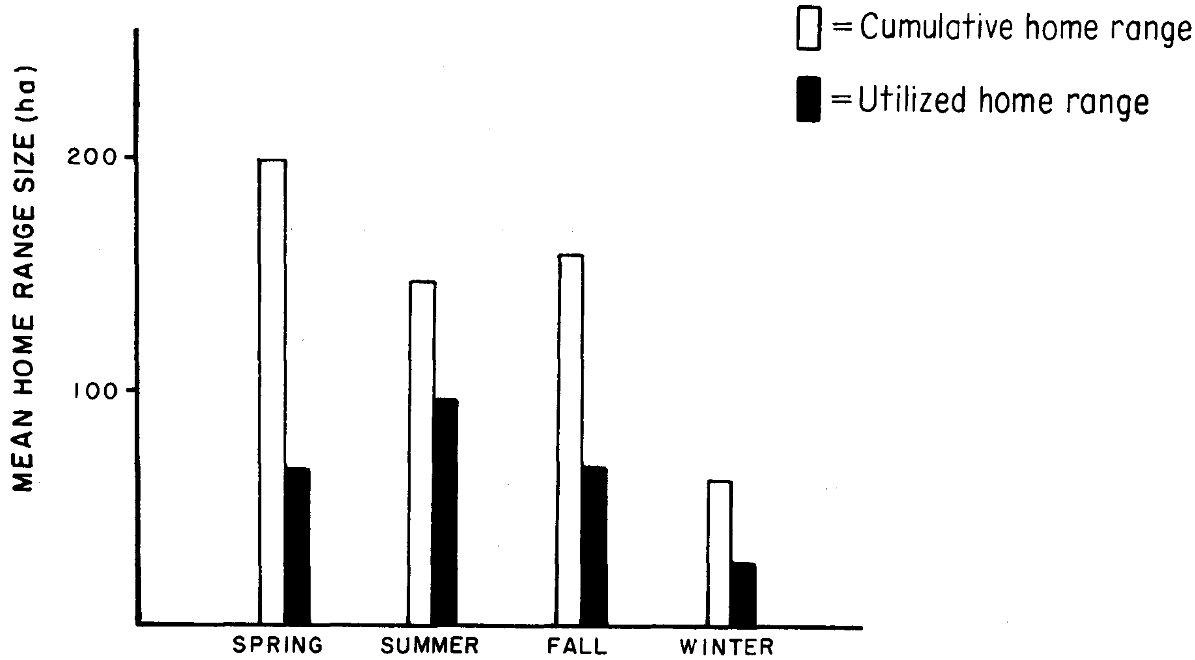

Figure 7.—Mean cumulative and utilized home range sizes for 27 lake trout in Twin Lakes, Colorado, during different seasons of 1977 and 1978.

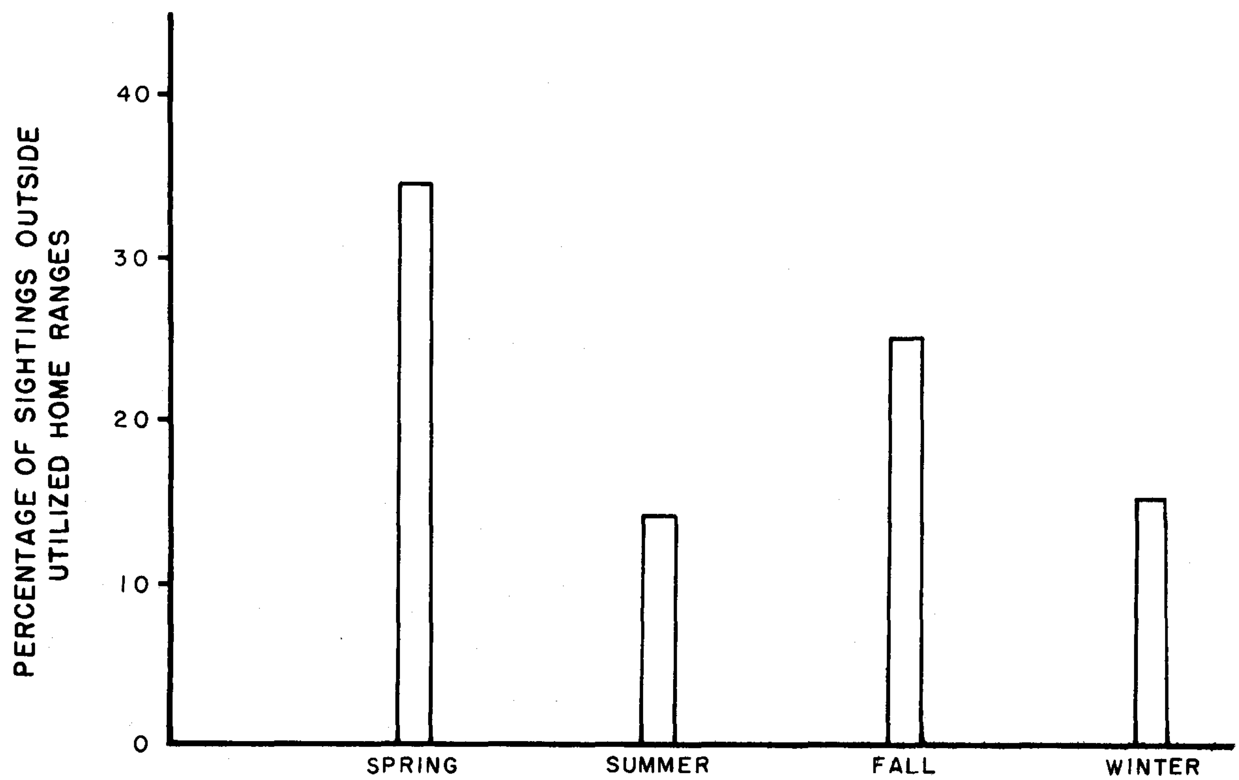

Figure 8.—Percentage of sightings found outside of 27 lake-trout-utilized home ranges in each season of the year at Twin Lakes, Colorado, during 1977 and 1978.

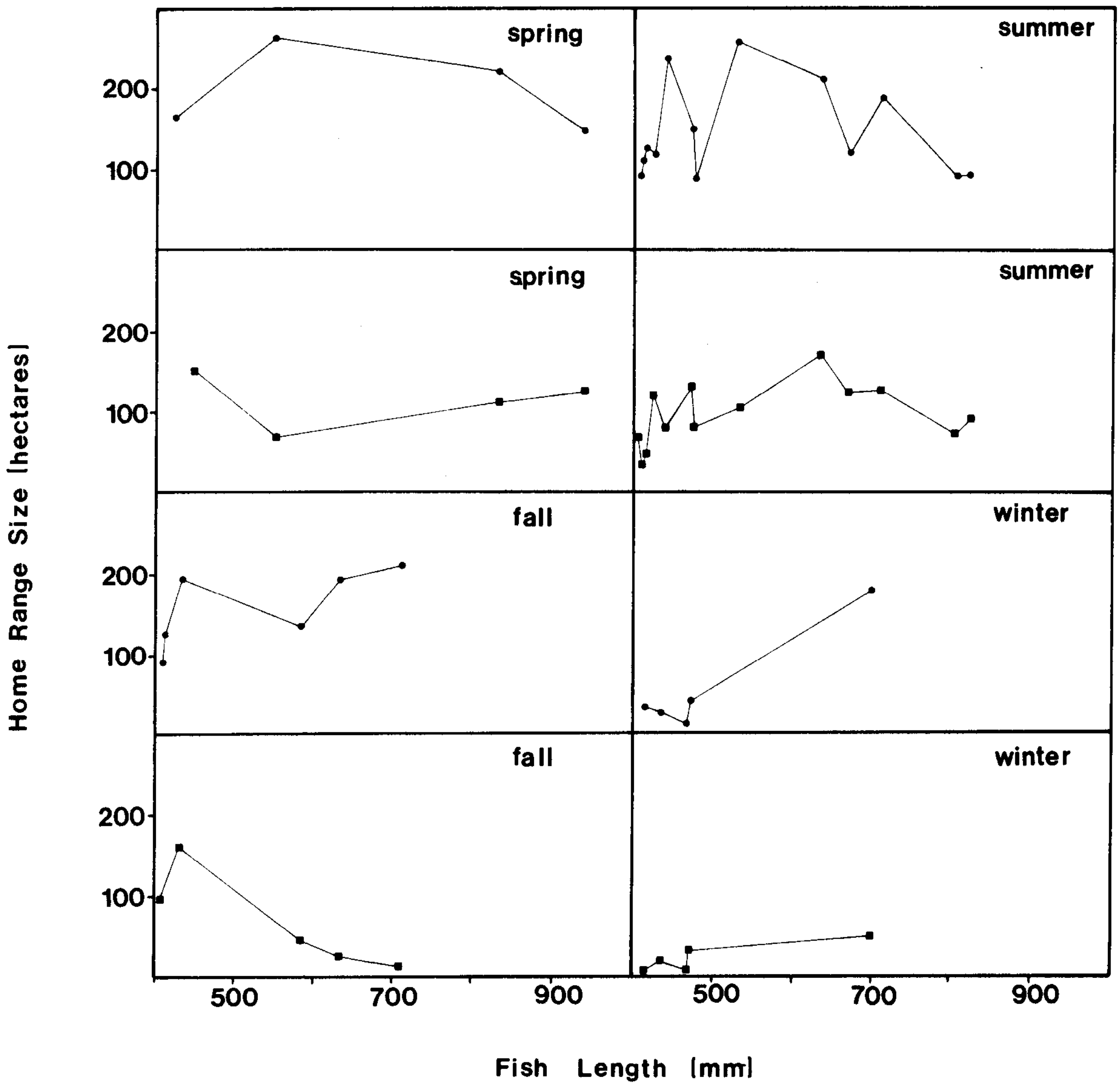

Figure 9.—The relationship of lake trout cumulative and utilized home ranges in Twin Lakes, Colorado, during 1977 and 1978, to the total length of lake trout. Dots represent cumulative home ranges and squares represent utilized home ranges.

of fish (Gunning and Shoop 1963; Minor and Crossman 1977 [29, 56]). The lack of any relationship between fish size and home range size in Twin Lakes was probably due to the individualistic movement patterns of lake trout, the relatively small size of the lakes, the small number of fish sampled, and the limited size range of tagged fish.

Forty percent of the lake trout tracked in the lower lake during the summer, fall, and winter had home ranges which extended to the vicinity of the powerplant tailrace. In the spring 75 percent of the tagged fish in the lower lake occupied home ranges near the powerplant.

Examination of the data plots also indicated that most lake trout spent very little time in the eastern third of the lower lake. Only 82 of the 1247 sightings obtained from fish in the lower lake were in the eastern third of the lake. Most of these sightings (47 of the 82) were obtained from spawning lake trout or from fish No. 21. The lack of use of the eastern third of the lower lake by most lake trout, except spawners, is probably due to an interaction of depth and water temperature preferences.

Fish Nos. 31, 38, 39, 42, and 46 from the upper lake, in contrast to the fish from the lower lake, utilized essentially all of the upper lake as home range (app. F). Tagged lake trout in the upper lake never moved through the connecting channel into the lower lake. However, two lake trout tagged in the lower lake moved into the upper lake. Movements of lake trout from the lower lake to the upper lake occurred when surface water temperatures were less than 11 °C.

Standard Gill Netting

Examination of gill net catch rates indicated seasonal changes in catch rates at the same station and possible differences in catch rates between stations within the same season (fig. 10). Significant (alpha = 0.05) seasonal and station differences in gill net catch rates were found using a two-way analysis of variance (app. H). However, a station-by-season interaction was also present. Kruskal-Wallis and Friedman nonparametric analyses by ranks were also conducted due to heterogeneity of variance among cells in the two-way analysis of variance. Significant seasonal differences in gill net catch rates and near significance for station differences in gill net catch rates within a season were found (app. D).

Station differences within the same season were examined by one-way analyses of variance. No significant differences in gill net catch rates between stations were obtained during the fall or spring (app. H). Significant differences (alpha = 0.05) in the gill net catch rates between stations were apparent during the winter and summer (app. H).

Differences in mean catch rates between stations in winter and summer were tested by multiple mean tests. No significant differences in gill net catch rates between stations were apparent during the winter. This result is a contradiction of the one-way analysis of variance result for winter catch rates and is due to the nature of the multiple mean test and the wide variance estimates for catch rates in the winter. During the summer the deepest station (station 6) in the lower lake had a significantly higher (alpha = 0.05) catch rate than all other stations. Other investigators have also found that lake trout are most likely to be caught in deeper cooler water during the summer months (Martin 1951; Rawson 1961; Galligan 1962; Hanson and Cordone 1967; Nolting 1968 [50, 67, 22, 32, 59]).

Comparisons of mean gill net catch rates at a given station during different seasons were accomplished using multiple mean tests. Generally, stations which were shallow had a higher gill net catch rate during the spring and fall than during the summer or winter. Station 4, located at the head of the tailrace channel, had significantly higher (alpha = 0.05) gill net catch rates during the spring and fall than during the summer or winter. The low catch rate in shallow water during the summer was probably due to low utilization of the warm water by lake trout. During the winter the low gill net catch rate could have been due to a total lack of activity at night or low utilization of the area by lake trout.

Shoreward Movements

Shoreward movements (movements to within 15 m of shore) were observed on 38 different occasions for 13 of the 34 tagged lake trout (table 4). Over 60 percent of the 22 sightings obtained close to shore during ice-free seasons occurred between 0600 and 1300 hours (fig. 11). No shoreward movements were recorded at night (2230-0500), except during spawning.

Large lake trout made shoreward movements more frequently than small lake trout. With one exception, all of the fish that demonstrated shoreward movements during the ice-free seasons were more than 550 mm in length, even though a greater number of fish less than 550 mm were tracked during this time. During the months of May and November the Colorado Division of Wildlife has found that the average size of lake trout captured in 5 of 11 gill nets, set at depths of less than 15 m, was significantly larger than for nets set at depths greater than 15 m (Personal communication, Tom Nessler, Colorado Division of Wildlife).

Shoreward movements in the winter were somewhat different. Fish tended to move close to shore during the early morning and late afternoon hours (fig. 11). All lake trout observed during the winter exhibited shoreward movements regardless of size.

Vertical Distributions and Temperature Preferences

Seventeen of 24 (71 percent) lake trout captured by vertical gill netting were captured within 3 m of the bottom (fig. 12). Water temperatures at the depth from which lake trout were taken are also shown in figure 12. None were captured in water warmer than 14.2 °C.

Table 4.—*Shoreward movements of 13 lake trout from Twin Lakes, Colorado, at various times of the day and different seasons during 1977 and 1978*

Fish No.	Length (mm)	Season	Time of day observed close to shore
27	942	spring	1330
29	550	spring	1020
29	550	spring	2250
29	550	spring	0825
31	670	summer	1225
31	670	summer	0635
35	805	summer	1145
35	805	summer	1000
36	635	summer	2015
36	635	summer	1020
38	475	summer	0715
39	820	summer	0710
39	820	summer	1825
39	820	summer	0930
39	820	summer	0815
8	711	fall	0920
31	670	fall	1615
36	635	fall	1540
36	635	fall	0840
36	635	fall	0840
36	635	fall	0920
38	475	fall	1000
21	473	winter	1600
23	435	winter	0640
23	435	winter	1745
24	457	winter	0745
24	457	winter	1718
24	457	winter	0745
25	700	winter	1232
25	700	winter	1718
25	700	winter	1052
25	700	winter	1150
25	700	winter	1725
25	700	winter	1215
25	700	winter	1230
25	700	winter	1515
26	416	winter	0821

Lake trout tagged with temperature-sensitive tags were found to make excursions into water as warm as 15.4 °C. Excursions into warm water were also found by Martin (1951) and Galligan (1962) [50, 22], who felt that such excursions into warm water by lake trout were related to feeding. When excursions into warm water have not been observed, adequate forage in the cool water regions has been present (Rawson 1961; Hanson and Cordone 1967 [67, 32]).

Krieger (1979) [43] found that during the summer months at Twin Lakes most white suckers were found at depths where water temperatures exceeded 12 °C. Rainbow trout were also captured where water temperatures exceeded 12 °C. These two species are the main forage items for lake trout longer than 550 mm in Twin Lakes (Griest 1977) [28]. Thus it seems likely that movement of lake trout larger than 550 mm into water warmer than 12 °C is related to feeding.

The 24 lake trout captured in vertical gill nets in the lower lake were taken at depths where water temperatures averaged 10.5 °C. The mean water temperature obtained in the lower lake from sightings of lake trout tagged with temperature tags was 10.5 °C. Tagged fish in the upper lake occupied depths where water temperatures averaged 8.5 °C. Previous researchers found that the temperature of the water most frequently occupied by lake trout ranged from 8.5 to 11.8 °C (Rawson 1961; Nolting 1968; McCauley 1970 [67, 59, 53]).

Data on the selection of temperature, distance off the bottom, and depth for tagged lake trout are shown in appendix I. Telemetry data from tagged fish showed some variations in individual selection of temperature, depth, and the distance off the bottom. Selected temperatures ranged from 6.6 to 15.4 °C, while depths selected ranged from 3.0 to 23.0 m and the distance off the bottom ranged from 0.3 to 16.3 m. When data for all the tagged lake trout were pooled, it was apparent that lake trout spent most of the time within 3 m of the bottom where water temperatures were less than 12 °C (fig. 13).

No trends in daily vertical movements were apparent for any of the lake trout tagged with temperature-sensitive tags; rather, changes in vertical distributions occurred during all times of the day (app. I). Previous researchers working with other salmonids have found that some species exhibit predictable vertical migrations, while others do not (Finnell 1968; Engel and Magnuson 1976; Maclean 1976 [20, 15, 48]).

Lake trout have been found to be primarily bottom-dwelling fish in some studies (Galligan 1962; Nolting 1968; Chiotti 1973 [22, 59, 7]), while other investigators have found lake trout in mid-water areas (Van Oosten 1943; Brazo and Liston 1977; Wells 1977 [85, 6, 87]).

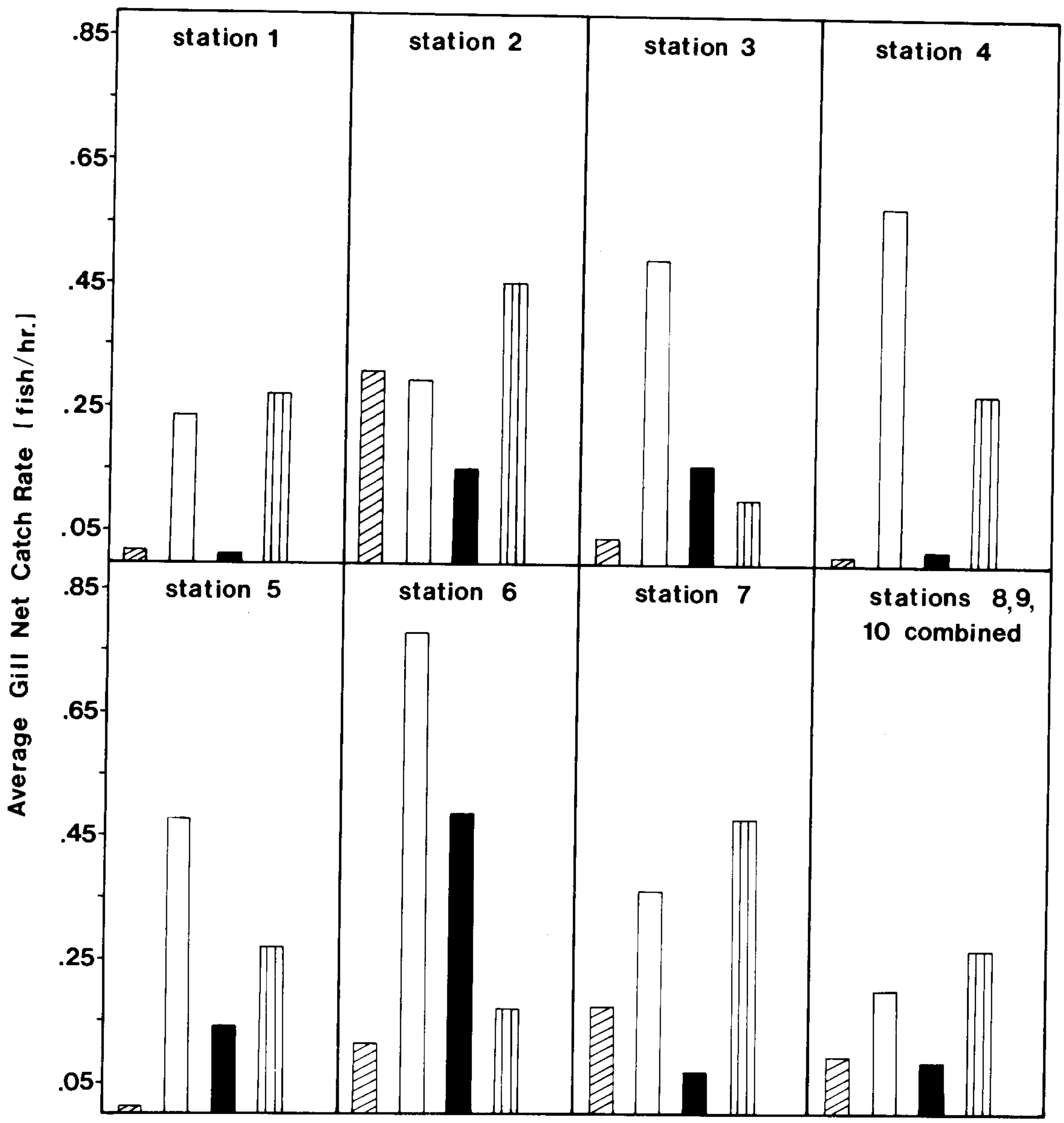

Figure 10.—Mean gill net catch rates of lake trout at 10 stations in Twin Lakes, Colorado, during winter, spring, summer, and fall of 1978. Diagonal lines represent winter, clear represents spring, solids represent summer, and vertical lines represent fall.

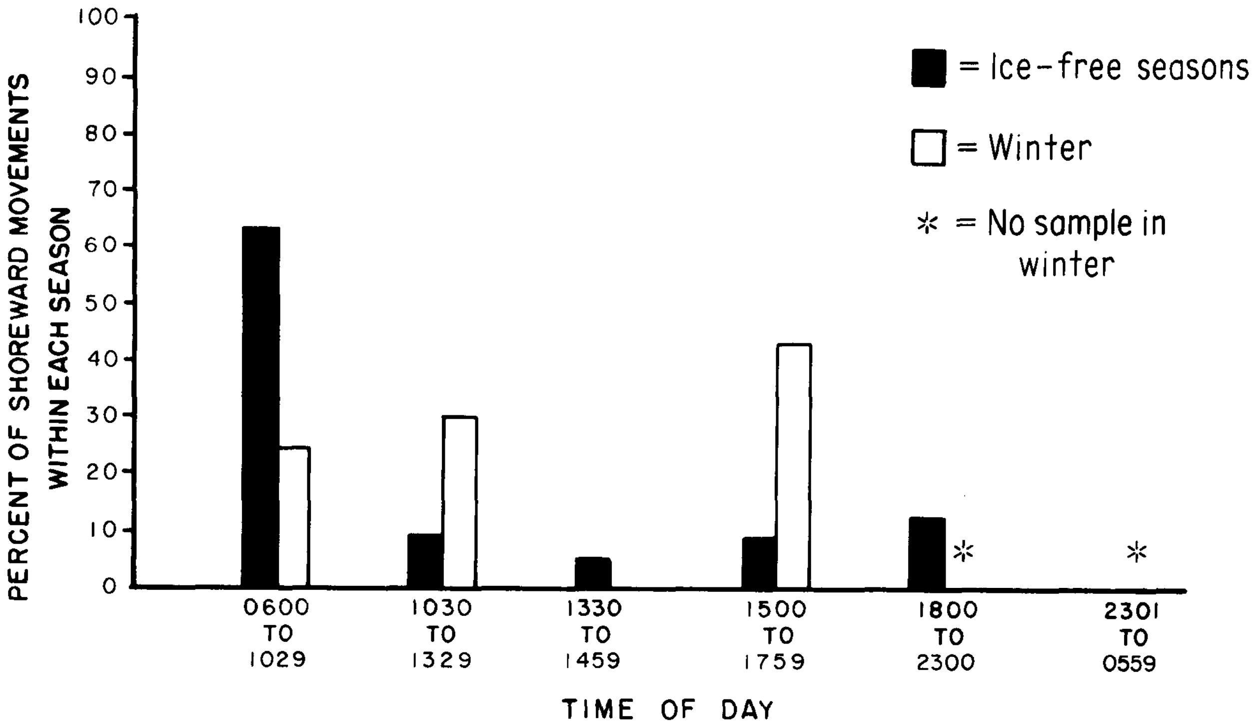

Figure 11.—Percentages of shoreward movements of tagged lake trout in Twin Lakes, Colorado, that occurred during different times of the day in the winter and during ice-free seasons of 1977 and 1978.

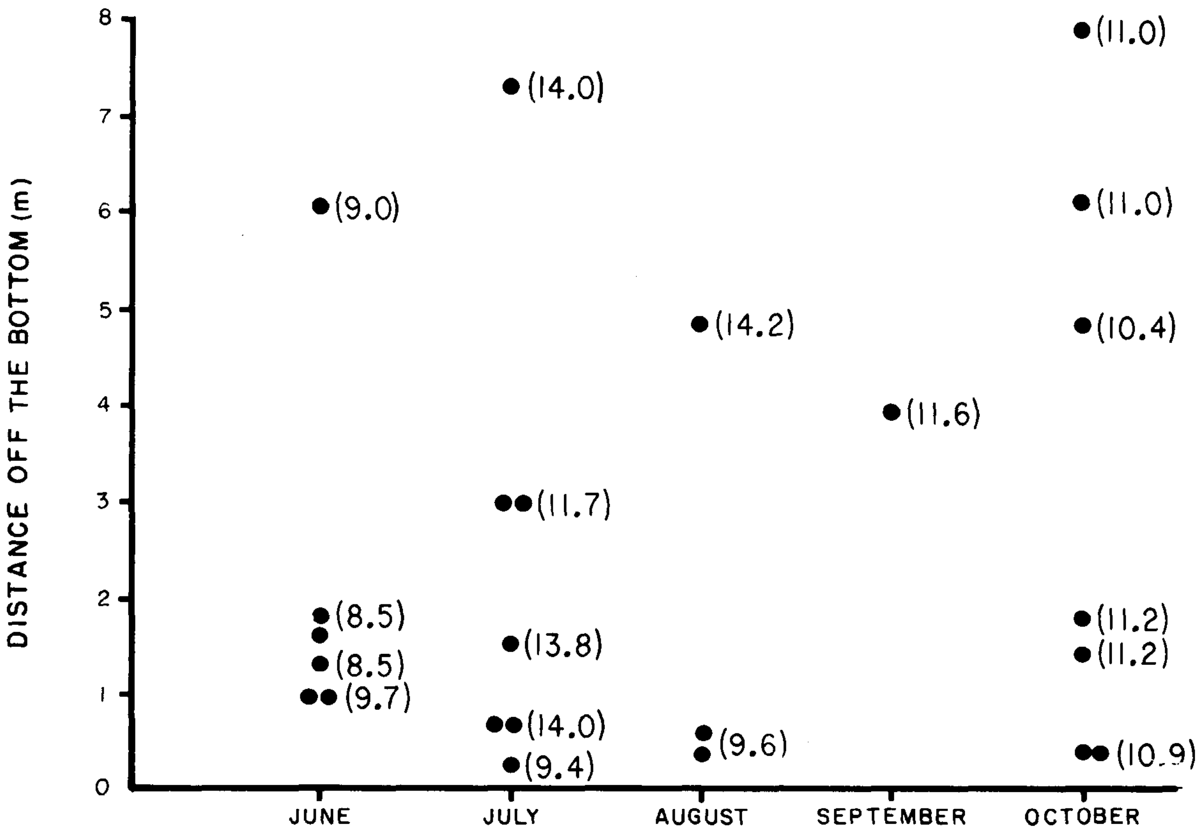

Figure 12.—Distance off the bottom and temperature distributions of 24 lake trout captured by vertical gill nets in Twin Lakes, Colorado, during 1978. Temperatures at which fish were captured are shown in parentheses and are given in degrees Celsius. Dots represent individual fish.

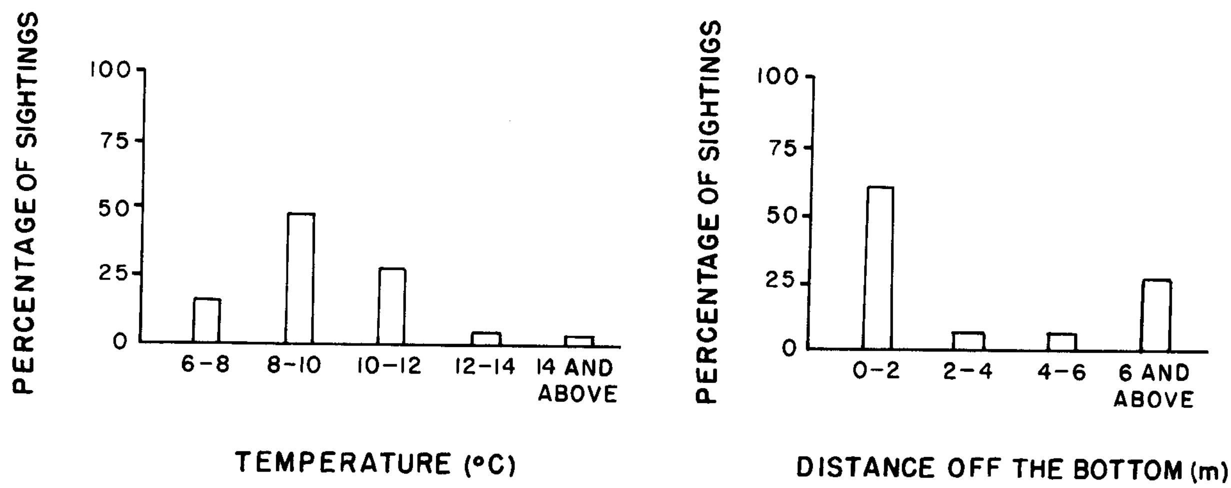

Figure 13.—Distance off the bottom and temperature distributions of lake trout tagged with temperature-sensitive transmitters between July and September 1978 in Twin Lakes, Colorado.

It is possible that lake trout found in mid-water areas in Twin Lakes were searching for food. Rainbow trout and white suckers have been shown to be utilized as food by lake trout in Twin Lakes (Griest 1977 [28]). Rainbow trout were not captured in mid-water areas of Twin Lakes during vertical gill netting operations, but several suckers were (Krieger 1979 [43]). However, no large lake trout were taken in the vertical gill nets and only one temperature-tagged lake trout (fish No. 35) spent significant amounts of time in mid-water areas. Several other large lake trout were captured by standard horizontal gill nets within 1 m of the bottom during the summer. It seems probable that occupation of mid-water depths by large lake trout is an individual movement characteristic that does not occur frequently at Twin Lakes.

Small lake trout (shorter than 550 mm) were found in mid-water depths. It is possible that these fish were searching for food. Mysid shrimp have been shown to move up into the water column during the night in all seasons of the year (Gregg 1976 [27]) and the importance of mysid shrimp in the diet of lake trout in Twin Lakes has been well documented (Griest 1977 [28]). However, because lake trout movements into mid-water depths were found to occur during all times of the day, it was felt that the feeding explanation did not totally account for movements of lake trout smaller than 550 mm into mid-water areas.

Spawning Distributions

It was apparent from the analysis of the gill net catch that lake trout were not using the western one-third of the lower lake or the powerplant tailrace area for spawning. The numbers of spawning trout captured at various locations are shown on figure 14.

During the last 2 weeks of October and the first week of November of 1977 and 1978, ripe spawners were captured by gill nets in water ranging in depth from 1.5 to 12 m. These fish ranged in size from 375 to 1008 mm total length. Electrofishing of the shoreline areas at night during the peak of spawning failed to yield any ripe lake trout. It is possible that the fish moved out into deeper water before they were affected by the electrical field.

Shoreward movements of spawners did occur, as several spawners were captured in gill nets very close to shore. However, trends in shoreward movements were not apparent from examination of telemetry data from ripe lake trout.

Examination of home range data from five ripe lake trout indicated that males covered larger areas than females (fig. 15). In addition, ripe lake trout which were tagged (fish Nos. 12, 47, 48, and 49) did not utilize the western one-third of the lower lake.

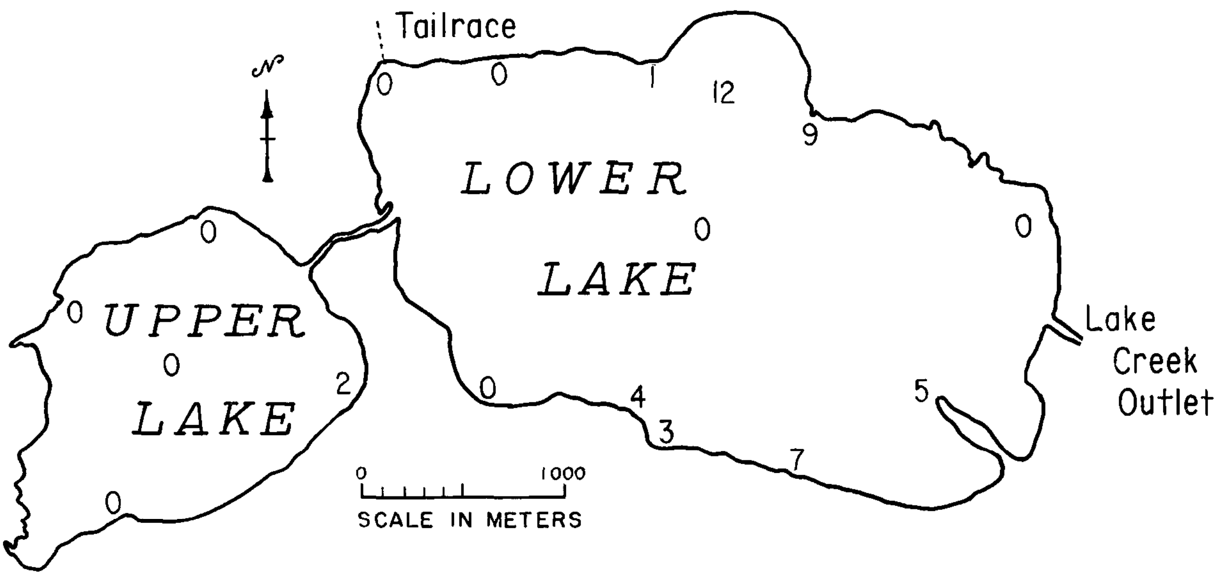

Figure 14.—Numbers of ripe lake trout captured by gill nets from various locations in Twin Lakes, Colorado, during October and November of 1977 and 1978.

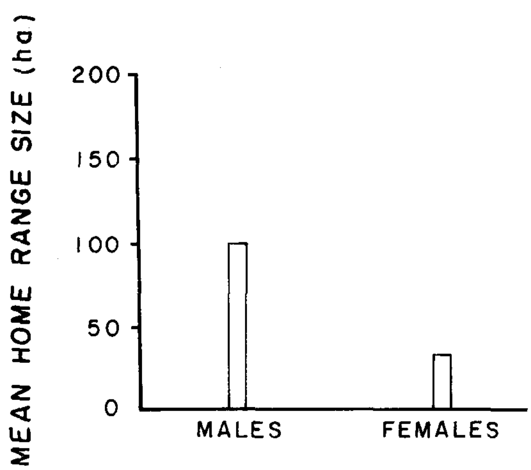

Figure 15.—Estimates of the mean home range sizes of male and female lake trout during October and November of 1977 and 1978 in Twin Lakes, Colorado.

Two ripe lake trout were tagged with temperature-sensitive transmitters (fish Nos. 46 and 47). The mean temperature from all sightings on these two fish was 8.4 °C. These fish had a choice of water temperatures between 7.2 and 11.5 °C. Other investigators have found that lake trout spawned when water temperatures were in the range of 8 to 10 °C (Eschmeyer 1954; Martin 1955; Rawson 1961; McCrimmon 1963 [17, 51, 67, 55]). Depth of spawning has been found to range from 150 mm to 61 m (Royce 1951; Galligan 1962; Deroche 1969 [70, 22, 10]). Nolting (1968) [59] suggested that lake trout in Twin lakes spawned at depths ranging from 2 to 10 m, during October and November. He also captured ripe lake trout in many of the same areas in which they were found in the present study.

Distribution of Juvenile and Young-of-the-Year Lake Trout

Efforts to determine the distribution of lake trout less than 230 mm in length were not highly successful. During the course of this study only 12 lake trout (which had not been stocked by the Colorado Division of Wildlife) between 150 and 230 mm in length were captured in over 400 hours of netting efforts with small mesh gill nets. Nine of the small lake trout were captured during the summer months in water deeper than 15 m and within 1 m of the bottom. The other three were captured during the winter at locations where the water depth ranged from 3 to 10 m. All the small lake trout were captured in areas occupied by adult and large immature lake trout. Extensive otter trawling yielded one lake trout 60 mm in length. This one fish was captured near a rocky outcrop at a depth of approximately 13 m. Unfortunately, no trawling was conducted at depths greater than 14 m.

Galligan (1962) and Griest (1977) [22, 28] also had little success capturing lake trout ranging in size from 50 to 240 millimeters with gill nets. However, numerous other researchers have captured lake trout in the above-mentioned size range by trawling near the bottom in water deeper than 18 m (Eschmeyer 1954; Dryer 1966; Deroche 1969; Pycha 1977 [17, 12, 10, 65]).

No information was collected on the movement of lake trout fry in the present study. In other studies lake trout eggs were found to hatch between January and June (Martin 1955; Martin 1960 [51, 52]). In situations similar to Twin Lakes hatching was found to occur in February or March, with the fry leaving the spawning rubble by early June (Royce 1951; Martin 1955; Deroche 1962 [70, 51, 9]). Deroche (1969) [10] found that lake trout fry moved immediately to deep water after they left the spawning rubble. Other investigators have also captured lake trout fry in deepwater areas (Royce 1951; Eschmeyer 1954; Pycha 1977 [70, 17, 65]).

McCauley (1970) [53] found that yearling lake trout preferred water temperatures of 11.8 °C, while Goddard et al. (1974) [25] found that yearling lake trout preferred water temperatures of 11.6 °C. Thus, if the findings concerning temperature, depth, and bottom preferences of young-of-the-year and juvenile lake trout are applicable to Twin Lakes, it seems reasonable that these small lake trout will most likely be found within 2 m of the bottom where water temperatures are less than 11.8 °C.

Numerous lake trout fingerlings, stocked by the Colorado Division of Wildlife, were captured in the vicinity of the tailrace during electrofishing efforts in October 1978. These fingerlings had been stocked at a location approximately 1.7 km away from the tailrace channel.

Homing

Gerking (1959) [23] defined homing as the return to an area previously occupied rather than moving to another equally likely spot. Homing movement during spawning has been recorded for several lake trout populations (Eschmeyer 1954; Martin 1960; Deroche 1962; Rahrer 1968 [17, 52, 9, 66]).

In this study numerous tagged lake trout that were displaced from the point of capture returned to the general area where they had been captured (fish Nos. 2, 27, 28, 31, 33 and 43). In addition, two ripe male trout displaced during the spawning season exhibited homing behavior (fish Nos. 12 and 50). However, not all fish which were displaced from their point of capture exhibited homing tendencies (fish Nos. 3, 29, and 30). It is possible that these fish were on excursions outside of their home range when they were captured. Shepherd (1973) [74] found that cutthroat trout made extensive excursions throughout a lake even though the fish occupied very restricted areas most of the time. Similar movements have been observed for largemouth bass (Winter 1977) [89].

SUMMARY

1. During the spring, summer, and fall, tracked lake trout were least active during the period from 2230 to 0500 hours.
2. During the winter, movement rates were constant throughout the day, except for an increase in activity between 1500 and 1800 hours. No data were collected on night movements in the winter.
3. Movement rates were not significantly correlated with the size of lake trout.
4. The mean seasonal movement rate during the fall was significantly lower than the movement rate during the summer.
5. Cumulative and utilized home ranges of lake trout were smaller in the winter than during other times of the year.
6. Tagged lake trout spent more time outside of their utilized home ranges during the spring and fall than during the summer or winter.
7. At least 40 percent of the home ranges in the lower lake included an area relatively close to the powerplant tailrace.
8. Home range size was not related to fish size.
9. Tagged lake trout from the upper lake did not move to the lower lake.
10. Two tagged trout from the lower lake moved to the upper lake.
11. During the summer, the gill net catch rate was significantly lower in shallow water than in the deep water areas.
12. Gill net catch rates from the tailrace channel during the summer and winter were significantly lower than the gill net catch rates during the spring and fall.
13. During the spring, summer, and fall most shoreward movements occurred between 0600 and 1300 hours, predominantly by

fish larger than 550 mm. Shoreward movements were not observed at night, except during spawning.
14. During the winter, shoreward movements occurred most frequently just before sunset.
15. Lake trout were usually found within 3 m of the bottom where water temperatures were less than 12 °C.
16. Between June and October 1978, lake trout in the lower lake were found to occupy depths where water temperatures averaged 10.5 °C.
17. All ripe lake trout captured in the lower lake were taken in the eastern two-thirds of the lower lake, at depths ranging from 1.5 to 12 m. None were captured in the vicinity of the tailrace channel.
18. Spawning occurred during the last two weeks of October and the first week of November during 1977 and 1978.
19. Homing of displaced ripe lake trout to capture locations was observed.

CONCLUSIONS CONCERNING THE VULNERABILITY OF LAKE TROUT TO ENTRAINMENT

Factors Affecting Entrainment Rates

Hauck and Edson (1976) [34] stated that the entrainment of fish is least likely when fish activity is minimal. Serchuk (1976) [73] believed that the relative inactivity of yellow perch during the night pumping cycle of the Ludington Pumped-Storage Powerplant was a factor which could explain the relatively few numbers of yellow perch entrained. However, the probability of fish entrainment is a function of more than just movement rates. In this study the probability of lake trout entrainment was considered to be a function of factors such as seasonal movement rates, daily movement rates, time of powerplant pumping, seasonal movements into the tailrace area, home range locations and size, extent of excursions out of home range, timing of shoreward movements, water temperature preferences, attraction to currents, and feeding activities.

Movement Rates

Within a given season lake trout movement rates were similar; however, the mean summer movement rate was significantly greater than the mean fall movement rate. Based on seasonal movement rates alone, entrainment of lake trout would be least probable during the fall.

Based on daily activity patterns, during spring, summer, and fall, lake trout are probably least vulnerable to entrainment between 2230 and 0500 hours. The period of highest vulnerability will probably be between 0830 and 1130 during spring, summer, and fall, and between 1500 and 1800 during the winter.

Home Range

May and early June appear to be a critical time as far as the percentage of the lake trout population moving into the vicinity of the powerplant tailrace is concerned. Three of four tagged lake trout observed during this time period established home ranges relatively close to the tailrace channel. Considering the large home range size and the fact that lake trout tended to make more excursions outside of their home ranges in the spring, it seems reasonable to assume that the probability of lake trout entrainment will be high in the spring.

The vulnerability of lake trout to entrainment in the fall will probably be similar to that in the spring, as the size of home ranges and the number of excursions outside of home ranges were similar. A smaller percentage of lake trout occupied home ranges near the powerplant in the fall than during the spring, but this could have been due to a combination of the small sample size obtained and the individualistic behavior of tagged lake trout.

During the summer, 40 percent of the tagged fish moved into the vicinity of the tailrace channel, probably because water temperatures were not high enough to limit movement into the area. Deepwater areas, where bottom water temperatures did not exceed 11 °C, existed within 50 m of the tailrace channel. Lake trout were found to move into water as warm as 11 °C frequently; thus, numerous lake trout could move into the area adjacent to the tailrace channel during the summer and could possibly be attracted into the tailrace channel by currents or food availability once the powerplant begins operation.

In the summer, the other 60 percent of the tagged lake trout had home ranges which were restricted to the center of the lower lake and few excursions out of these home ranges occurred. Thus it is felt that the lake trout population as a whole, based on home range attributes, will be less vulnerable to entrainment during the summer than during the spring or fall.

Home range sizes of lake trout were much smaller during the winter than during other times of the year and few excursions outside of the home ranges occurred. Because of the reduced area occupied by lake trout in the winter, the probability that a given lake trout would move into the vicinity of the tailrace channel during the winter is probably less than during other times of the year.

How susceptible lake trout in the upper lake will be to entrainment is unknown. Only six fish from the upper lake were tracked and none of them moved to the lower lake. Water temperatures probably limit lake trout movement through the shallow connecting channel during midsummer and early fall; however, water temperatures are not limiting at other times of the year. Kennedy (1940) [41] observed mass movements of lake trout from one lake to another via a channel only 4 meters deep. He felt that these movements were a function of lake trout attempts to avoid high water temperatures in one of the lakes. Unless some factor causes the habitat of the upper lake to become unsuitable it does not seem likely that any mass movements from the upper lake to the lower will occur. Any movements between the lakes that do occur will most likely take place between October and late June.

Once the new Twin Lakes Dam is completed water levels will be somewhat higher, depending on the snowmelt of any particular year (U.S. Bureau of Reclamation 1975 [84]). When water levels are at their maximum it will be possible for lake trout from the upper and lower lakes to move from one lake to the other during all times of the year. During low water years movements between the lakes during the summer would be limited due to high water temperatures in the connecting channel.

Standard Gill Netting

Examination of gill netting data indicated that lake trout were much more likely to be found in the vicinity of the tailrace channel during the spring and fall than during the summer or winter. It is important to note that lake trout could move into the tailrace channel during most times of the year, assuming that their distribution is largely controlled by water temperatures. Bottom water temperatures at the head of the tailrace channel never exceeded 14 °C and lake trout were frequently found to make excursions into water of this temperature. Most of the summer bottom water temperatures in the tailrace channel did not exceed 11 °C. However, unless they are attracted to the tailrace channel by water currents or food supply, it seems unlikely that many lake trout will be entrained during the summer or winter.

Shoreward Movements

Based on the shoreward movement patterns of lake trout in Twin Lakes, it seems likely that, during the ice-free seasons, they will be least vulnerable to entrainment between 2230 and 0500 hours and most vulnerable between 0600 and 1300 hours. Except in the winter, large lake trout will probably be more susceptible to entrainment than small lake trout (less than 550 mm total length), as the large lake trout tended to make shoreward movements more frequently than smaller ones.

During the daytime in the winter the vulnerability of lake trout to entrainment will be highest between 1500 and 1800 hours. The probable vulnerability of lake trout at night in the winter is not known.

Spawning Movements and Distributions

Ripe lake trout were not found in the western one-third of the lower lake. Thus it seems unlikely that many spawners will be entrained.

It is possible that spawning lake trout will attempt to utilize the riprap in the tailrace channel as a spawning area in the future. Lake trout have been found to use artificially placed spawning beds (Martin 1955; Hacker 1956; Prevost 1956; Martin 1960 [51, 30, 64, 52]), riprapped dams (Hambly 1966 [31]), and new natural spawning habitat made available by an increase in water levels (Cuerrier 1954 [8]).

It is likely that trout in Twin Lakes will continue using the same spawning areas as in the past. Most lake trout populations have been found to return to the same spawning area each year (Eschmeyer 1954; Martin 1960; Deroche 1962; McCrimmon 1963; Rahrer 1968 [17, 52, 9, 55, 66]). There was some evidence of lake trout homing in the present study. If lake trout continue using the same spawning areas as they have in the past, use of the tailrace channel as a spawning area will not be a problem. Emplacement of artificial spawning rubble in the eastern end of the lower lake could help attract spawning lake trout away from the tailrace area. The effect of powerplant operations on spawning trout in the upper lake should be minimal unless there are extensive movements of spawners from the upper to the lower lake.

The magnitude and timing of water level fluctuations in Twin Lakes after the powerplant begins operation are important with respect to lake trout spawning. Historically, water levels in Twin Lakes have been at the minimum level in the fall, with little change in the water level until spring runoff. Operation of the Mt. Elbert Pumped-Storage Powerplant at full capacity will cause a maximum daily fluctuation of 0.67 m in the water level of Twin Lakes (U.S. Bureau of Reclamation 1975 [84]), based on a water elevation near the minimum operational pool level after Twin Lakes Dam is completed. This elevation is near the historical average water level for Twin Lakes. Thus, problems with water level fluctuations before and after completion of the Twin Lakes Dam will be somewhat similar.

If the entire forebay were drained to produce power, a 1.2-m increase in the water level of the lower lake could occur (U.S. Bureau of Reclamation 1975 [84]). If lake trout were to spawn in water 1 to 2 m deep when the water level was high, then serious losses of eggs could be expected when the water level was lowered back to the original elevation. Since natural reproduction has accounted for as much as 88 percent of the catch for a given year class (Griest 1977 [28]), serious losses of lake trout eggs could have a significant effect on the fishery.

Although more information is needed about the specific depths of egg deposition, most lake trout in Twin Lakes probably spawn at depths greater than 2 m. Thus, serious losses of lake trout eggs due to proposed maximum daily fluctuations (0.67 m) of the water level are unlikely (assuming no long-term drawdown in excess of 2 m occurs between October and May).

Currents

Major water currents will be formed during the pumping and generation modes of the powerplant (Rhone 1976 [68]). The effect these currents will have on fish distributions is not known. Greenback (1956) [26] reported that northern pike and carp moved with the flow of currents. If lake trout in Twin Lakes were to move with the flow of currents during the pumping cycle of the powerplant then numerous lake trout could be entrained. Numerous lake trout have been shown to leave the lakes via the Lake Creek outlet in the spring (Finnell and Bennett 1974 [20]), and Griest (1977) [28] felt that these fish may have been attracted by currents due to the high flushing rate of the lakes during spring runoff. Other investigators have found that rainbow, brown, and lake trout did not appear to be attracted by water currents near the Ludington Pumped-Storage Powerplant (Serchuk 1976; Brazo and Liston 1977 [73, 6]).

Lake Trout Feeding

During operation of the Mt. Elbert Powerplant some dead or injured fish probably will be found in or near the tailrace channel. Lake trout may feed on dead fish if readily available and thus may be attracted to this area. However, the Ludington Pumped-Storage Powerplant has been operating several years with no significant increases in the number of lake trout caught near the tailrace, except during spawning. Even during spawning, fewer lake trout were found within the tailrace channel than outside of it (Brazo and Liston 1977 [6]).

Mysid shrimp could also be attracted to the tailrace channel by an increase in food items such as dead fish. If mysids are attracted to the area then lake trout could also be attracted to the area by the high concentrations of mysids. However, Gregg (1976) [27] found that mysids avoided turbulence of the type that will occur during powerplant operations. Thus it is unlikely that many lake trout will be attracted to the tailrace area by high concentrations of mysid shrimp.

Vulnerability of Lake Trout Eggs and Young-of-the-Year to Entrainment

Lake trout eggs will probably not be vulnerable to entrainment due to the locations of spawning areas. Larval lake trout will be safe for the same reason until they emerge from the spawning substrate. In other localities larval lake trout have been found to move to deep water after emerging from the substrate (Deroche 1962) [9]. Thus, unless they move into the vicinity of the tailrace it seems unlikely that many larvae will be entrained. However, what was thought to be a large school of lake trout fry was observed in deep water near the tailrace by scuba divers (LaBounty et al. 1976 [45]). This could mean that larval lake trout do utilize the area adjacent to the tailrace. Serious entrainment losses of larval fish could occur during pumping operations if many larvae are overcome by the powerful currents that will occur near the tailrace.

Lake trout fingerlings stocked by the Colorado Division of Wildlife were found in the immediate area of the tailrace during electrofishing operations in October 1978. Serious entrainment losses of these fingerlings could occur during pumping operations of the powerplant unless these fish avoid the turbulence in the vicinity of the tailrace.

Overall Conclusion

When all the previously discussed factors affecting the entrainment of lake trout are taken into account and given equal weighting, it seems likely that entrainment of lake trout will be highest in the spring and fall, lower in the summer, and least in the winter. This is assuming that the lake trout do not change their distribution patterns after the powerplant begins operation and that the powerplant operates in the pumping mode during the night.

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APPENDICES

APPENDIX A

TWO-WAY ANALYSIS OF VARIANCE OF MOVEMENT RATES OF LAKE TROUT IN TWIN LAKES, COLORADO, DURING 1977 and 1978, EXCLUDING WINTER DATA

Source of Variation	Sum of Squares	DF	Mean Squares	F	Significance of F
Seasons	309,620.34	2	154,810.17	3.95	0.020
Day	1,115,843.99	4	278,960.99	7.12	0.001
Season x Day	376,006.60	8	47,000.83	1.20	0.296
Residual	33,033,689.00	843	39,185.87		
Total	35,014,396.08	857	40,856.94		

APPENDIX B

TWO-WAY ANALYSIS OF VARIANCE OF MOVEMENT RATES OF LAKE TROUT IN TWIN LAKES, COLORADO, DURING 1977 AND 1978, EXCLUDING NIGHT DATA, BUT INCLUDING WINTER DATA

Source of Variation	Sum of Squares	DF	Mean Squares	F	Significance of F
Seasons	179,548.86	3	59,849.62	1.30	0.272
Day	460,524.90	3	153,508.30	3.34	0.019
Season x Day	683,569.74	9	75,952.19	1.65	0.097
Residual	33,446,798.09	728	45,943.40		
Total	34,848,272.57	743	46,902.12		

APPENDIX C

CROSSBREAKDOWN OF MOVEMENT RATE DATA FROM LAKE TROUT IN TWIN LAKES, COLORADO, DURING 1977 AND 1978

Table C-1.—*Crossbreakdown of movement rate data, excluding night data, from lake trout in Twin Lakes, Colorado, during 1977 and 1978. Seasons 1, 2, 3, and 4 represent winter, spring, summer, and fall, respectively. Times 2, 3, 4, and 5 represent 0500-0829, 0830-1129, 1130-1759 and 1800-2229, respectively*

Mean / Count / Standard deviation	Time of Day 2	3	4	5	
Season 1	71.07	68.13	175.04	108.40	140.63
	7	19	57	3	86
	51.88	78.05	224.78	26.19	192.84
2	154.99	201.86	113.08	132.25	138.98
	19	21	60	16	116
	150.27	210.22	115.72	116.49	144.89
3	100.29	221.52	156.97	192.49	176.67
	45	94	183	41	363
	77.08	194.90	234.97	321.69	226.08
4	97.18	175.81	165.07	86.20	128.36
	28	35	52	64	179
	90.86	150.18	410.56	100.57	243.03
	108.23	192.36	153.61	127.83	152.07
	99	169	352	124	744
	99.39	183.84	252.62	206.90	216.57

Table C-2.—*Crossbreakdown of movement rate data, excluding winter data, from lake trout in Twin Lakes, Colorado, during 1977 and 1978. Seasons 2, 3, and 4 represent spring, summer, and fall, respectively. Times 1, 2, 3, 4 and 5 represent 2230-0459, 0500-0829, 0830-1129, 1130-1759 and 1800-2229, respectively*

Mean / Count / Standard deviation	Time of Day 1	2	3	4	5	
Season 2	88.05	156.99	201.85	113.07	132.25	124.75
	45	19	21	60	16	161
	77.46	150.26	210.22	115.72	116.50	131.94
3	121.61	100.29	221.52	156.97	192.49	160.84
	91	45	94	183	41	454
	155.07	77.05	194.90	234.98	321.69	214.49
4	49.53	97.18	175.82	165.07	86.21	107.59
	64	28	35	52	64	24
	42.78	90.86	150.18	410.56	100.57	
	90.99	111.06	208.10	149.47	128.31	138.99
	200	92	150	295	121	858
	117.32	101.71	187.49	257.79	209.42	202.13

APPENDIX D

RESULTS OF SOME NONPARAMETRIC TESTS ON MOVEMENT RATES, GILL NETTING, AND HOME RANGE DATA FROM LAKE TROUT IN TWIN LAKES, COLORADO, DURING 1977 AND 1978

Data tested	Test used	Test statistic	Critical value 5%	Significant (alpha = .05)
Seasonal movement rate data, excluding winter	Kruskal-Wallis one-way analysis	k = 34.4	5.78	Yes
Daily movement rate data, excluding winter	Friedman's analysis by ranks	x^2 = 8.27	9.4	Almost
Seasonal movement rate data, including winter	Kruskal-Wallis one-way analysis	k = 3.46	7.81	No
Daily movement rate data, including winter	Friedman's analysis	x^2 = 2.1	7.38	No
Gill netting, within seasons but different stations	Kruskal-Wallis one-way analysis	k = 12.42	16.9	Almost
Gill netting, between seasons	Friedman's analysis	x^2 = 150.83	7.81	Yes
Seasonal cumulative home range sizes	Kruskal-Wallis one-way analysis	k = 62.86	7.81	Yes
Seasonal utilized home range sizes	Kruskal-Wallis one-way analysis	k = 4.8	7.81	No

APPENDIX E

ONE-WAY ANALYSES OF VARIANCE OF MOVEMENT RATE DATA FROM LAKE TROUT IN TWIN LAKES, COLORADO, DURING ALL SEASONS OF 1977 AND 1978

Table E-1.—*One-way analysis of variance of movement rate data from lake trout in Twin Lakes, Colorado, during the spring of 1978*

Source of Variation	Sum of Squares	DF	Mean Squares	F	Significance of F
Between periods	214,297.99	4	53,574.50	3.28	0.013
Within periods	2,547,989.52	156	16,333.27		
Total	2,762,287.51	160			

Table E-2.—*One-way analysis of variance of movement rate data from lake trout in Twin Lakes, Colorado, during the summer of 1977 and 1978*

Source of Variation	Sum of Squares	DF	Mean Squares	F	Significance of F
Between periods	694,842.52	4	173,710.63	3.87	0.004
Within periods	20,146,733.84	449	44,870.23		
Total	20,841,576.37	453			

Table E-3.—*One-way analysis of variance of movement rate data from lake trout in Twin Lakes, Colorado, during the fall of 1977 and 1978*

Source of Variance	Sum of Squares	DF	Mean Squares	F	Significance of F
Between periods	582,710.09	4	14,567.52	3.35	0.011
Within periods	10,338,965.64	238	43,441.03		
Total	10,921,675.73	242			

Table E-4.—*One-way analysis of variance of movement rate data from lake trout in Twin Lakes, Colorado, during the winter of 1978*

Source of Variance	Sum of Squares	DF	Mean Squares	F	Significance of F
Between periods	204,348.65	3	68,116.22	1.89	0.138
Within periods	2,956,615.34	82	36,056.28		
Total	3,160,963.98	85			

APPENDIX F

SIGHTING LOCATIONS, CUMULATIVE AND UTILIZED HOME RANGES OF 34 LAKE TROUT IN TWIN LAKES, COLORADO, BETWEEN JULY 1977 AND NOVEMBER 1978

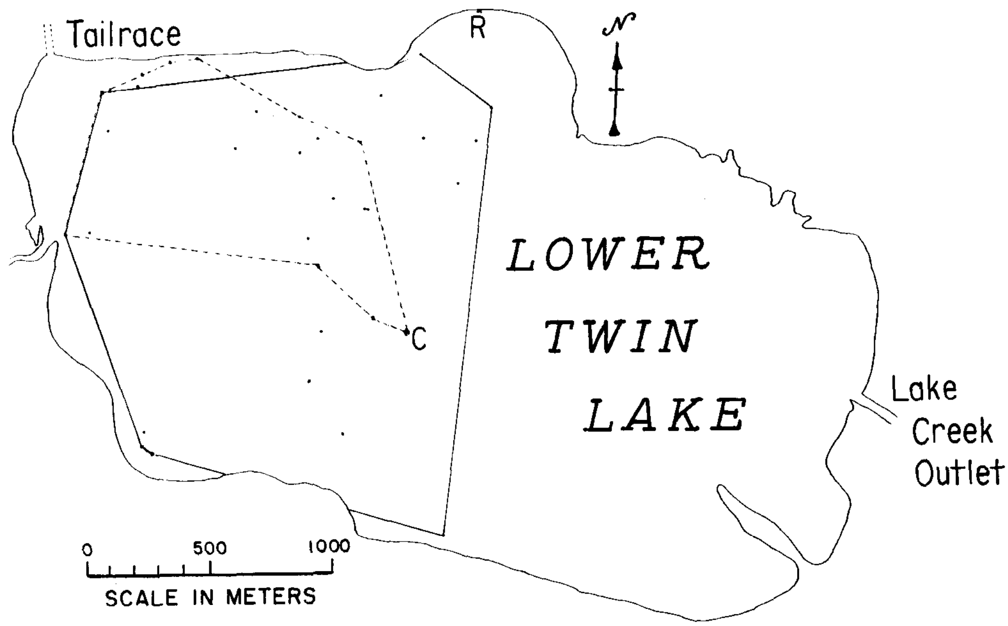

Figure F-1.—Sighting locations and cumulative and utilized home ranges of fish No. 2 in Twin Lakes, Colorado, during the summer of 1977. Sighting locations and cumulative and utilized home ranges are shown by dots, solid lines, and dashed lines, respectively. C represents the point of capture, while R represents the release point.

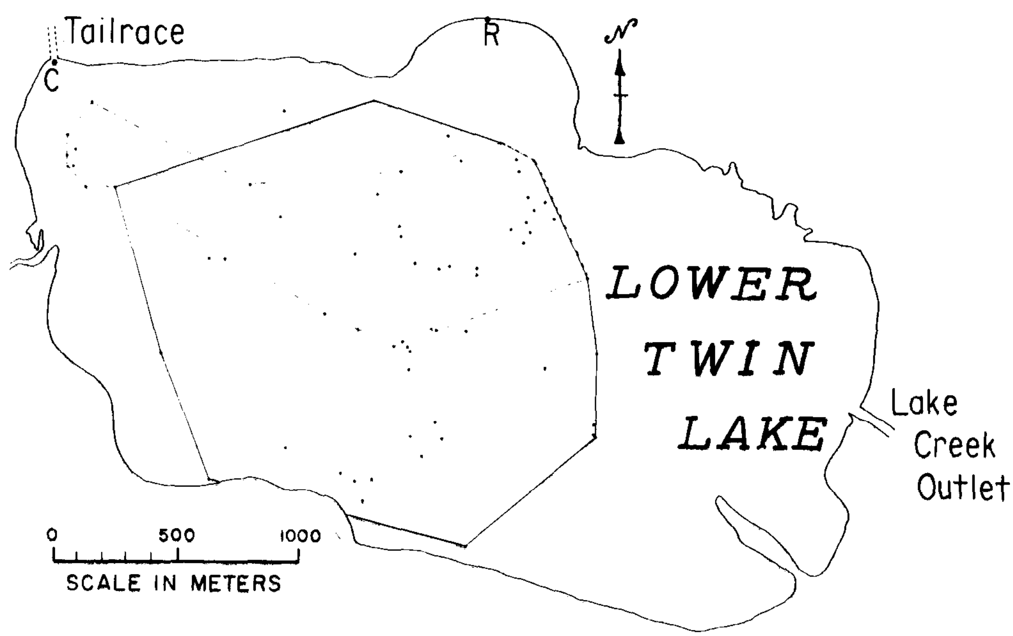

Figure F-2.—Sighting locations and cumulative and utilized home ranges (shown by dots, solid lines, and dashed lines, respectively) of fish No. 3 in Twin Lakes, Colorado, during the summer 1977. C represents the point of capture, while R represents the release point.

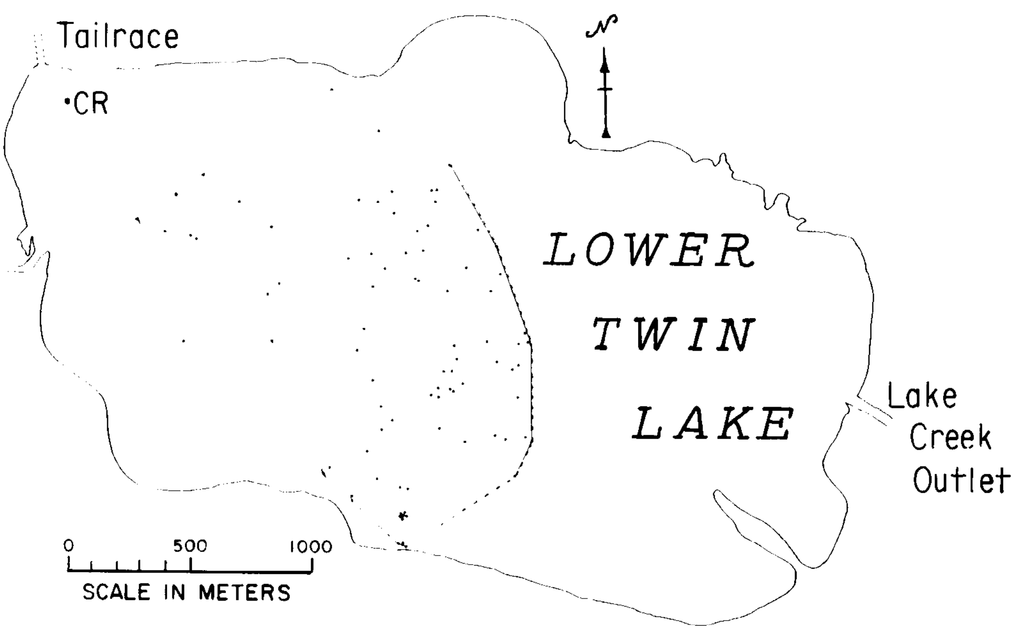

Figure F-3.—Sighting locations and cumulative and utilized home ranges (shown by dots, solid lines, and dashed lines, respectively) of fish No. 4 in Twin Lakes, Colorado, during the summer 1977. C represents the point of capture, while R represents the release point.

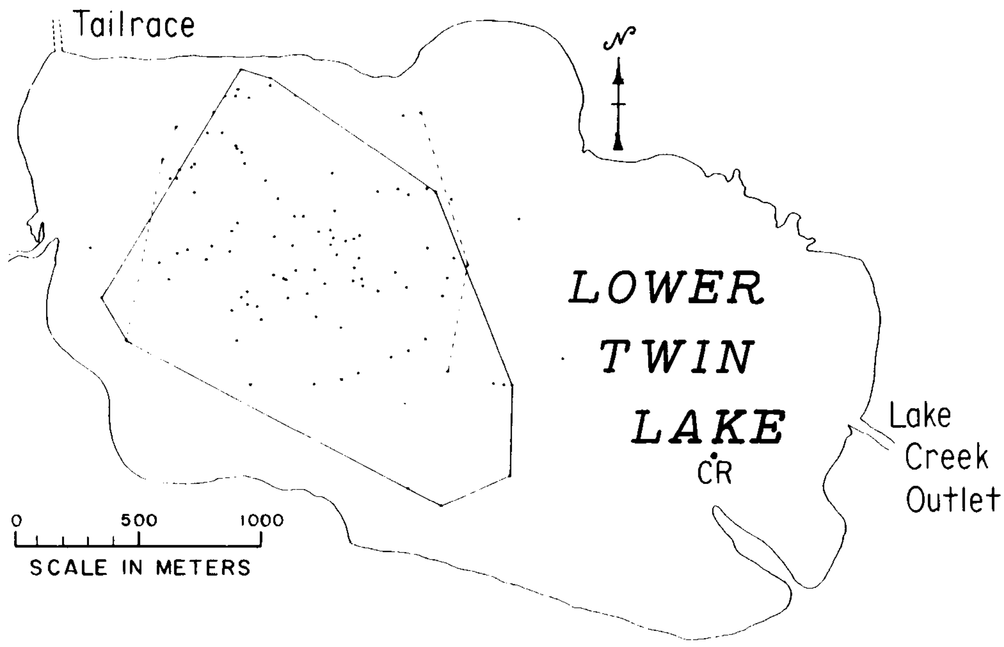

Figure F-4.—Sighting locations and cumulative and utilized home ranges (shown by dots, solid lines, and dashed lines, respectively) of fish No. 8 in Twin Lakes, Colorado, during the summer 1977. C represents the point of capture, while R represents the release point.

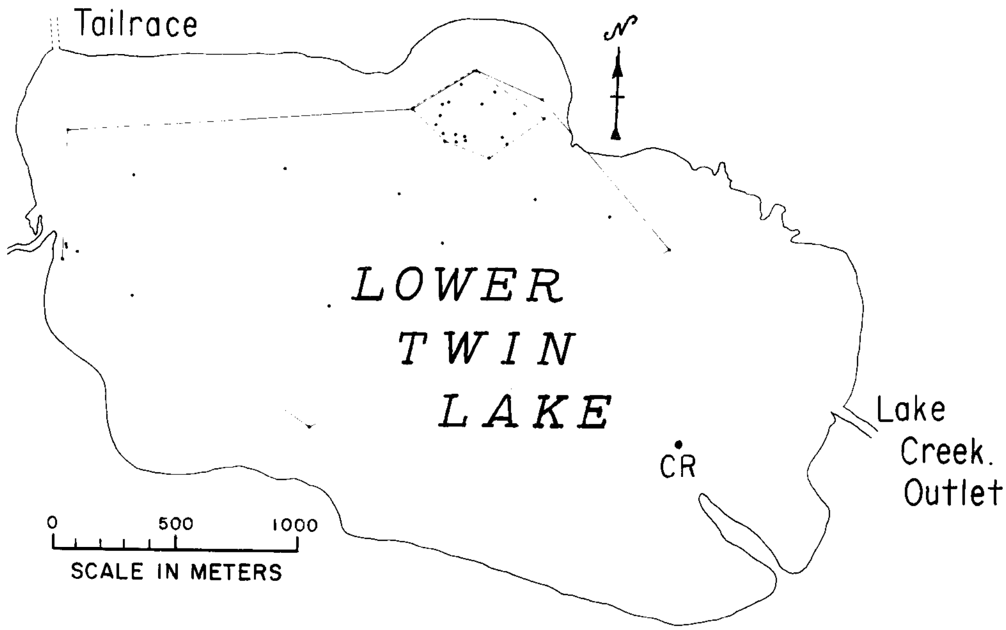

Figure F-5.—Sighting locations and cumulative and utilized home ranges (shown by dots, solid lines, and dashed lines, respectively) of fish No. 8 in Twin Lakes, Colorado, during the fall 1977. C represents the point of capture, while R represents the point of release.

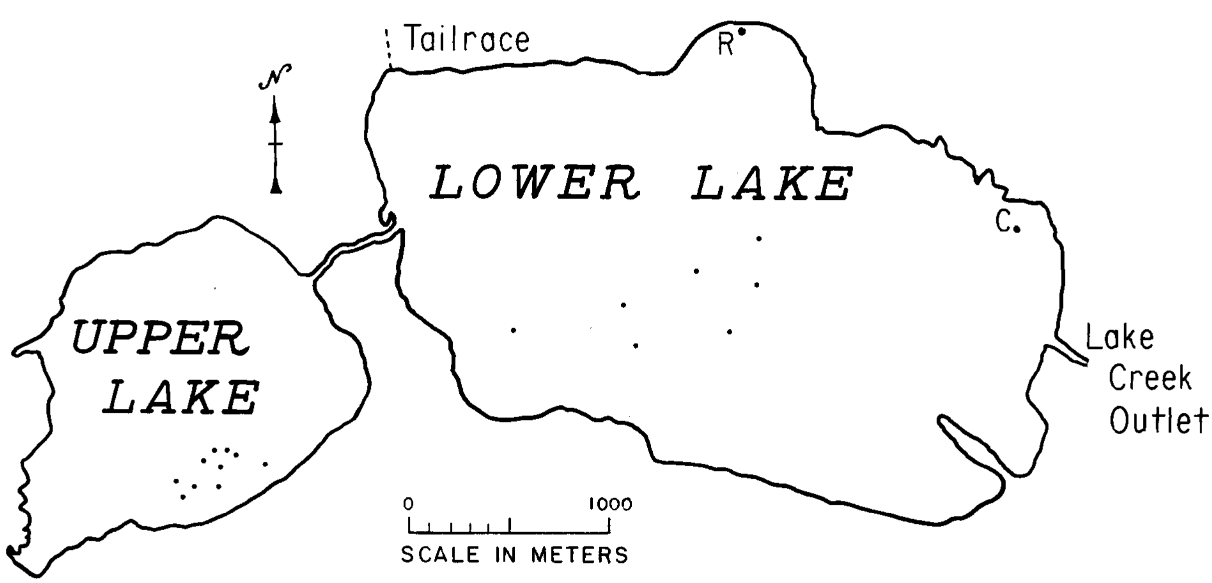

Figure F-6.—Sighting locations of fish No. 10 in Twin Lakes, Colorado, during the fall 1977. Sighting locations are shown by dots. C represents the point of capture, while R represents the point of release.

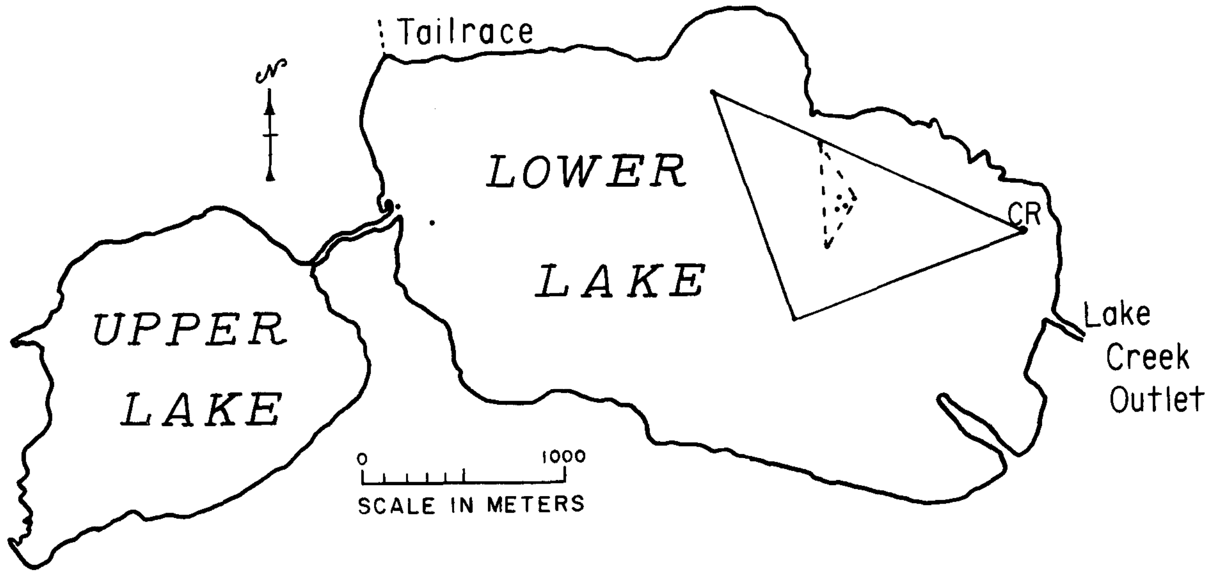

Figure F-7.—Sighting locations and cumulative and utilized home ranges (shown by dots, solid lines, and dashed lines, respectively) of fish No. 11 in Twin Lakes, Colorado, during the fall 1977. C represents the point of capture, while R represents the point of release.

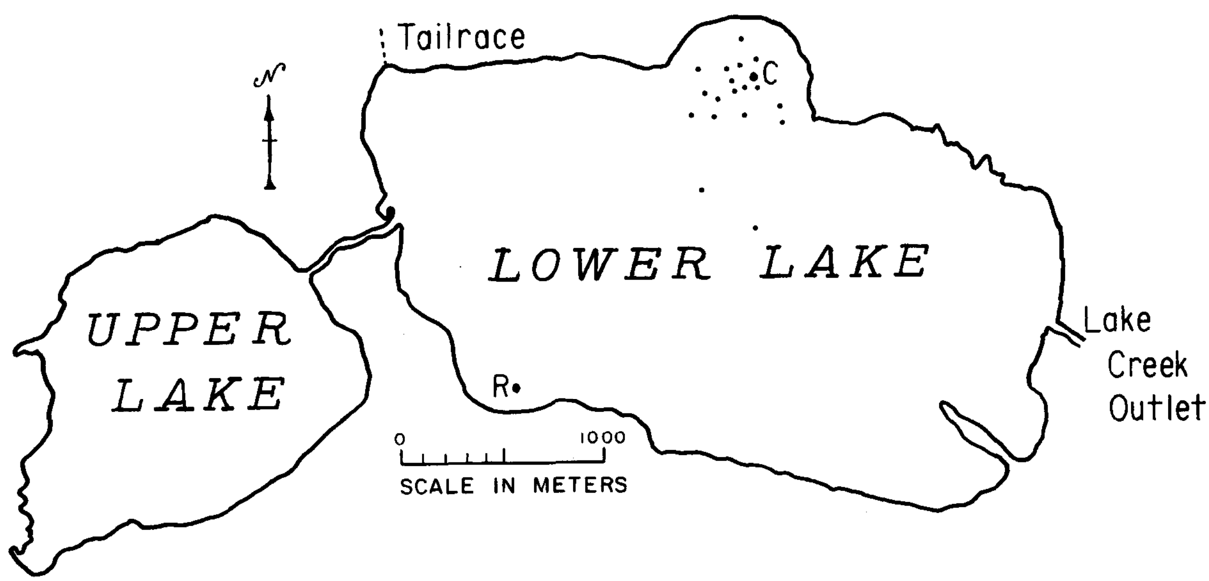

Figure F-8.—Sighting locations (shown by dots) of fish No. 12 in Twin Lakes, Colorado, during the fall 1977. C represents the point of capture, while R represents the point of release.

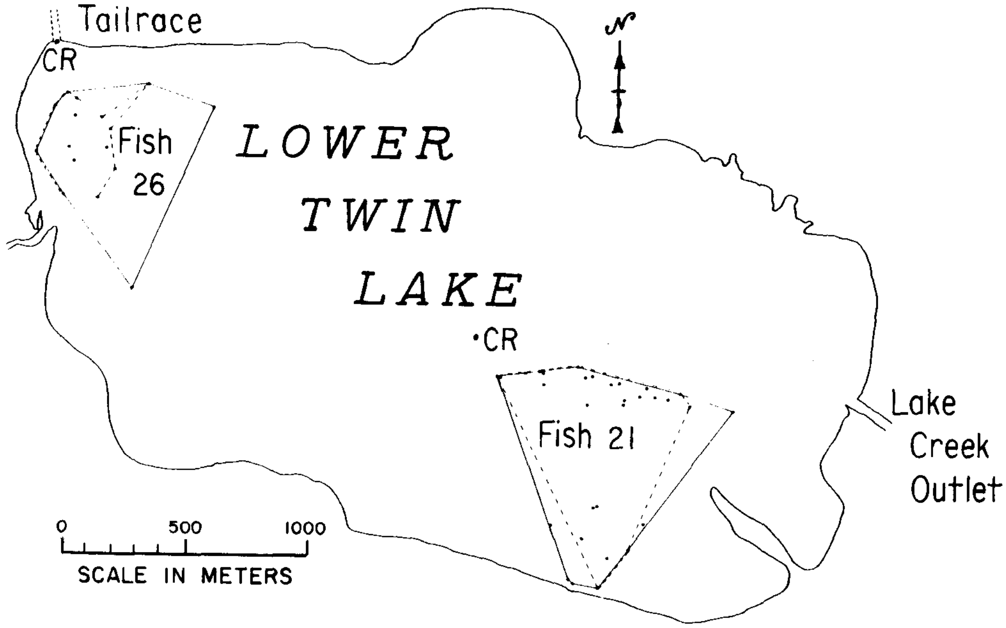

Figure F-9.—Sighting locations and cumulative and utilized home ranges (shown by dots, solid lines, and dashed lines, respectively) of fish Nos. 21 and 26 in Twin Lakes, Colorado, during the winter 1978. C represents the capture point, while R represents the point of release.

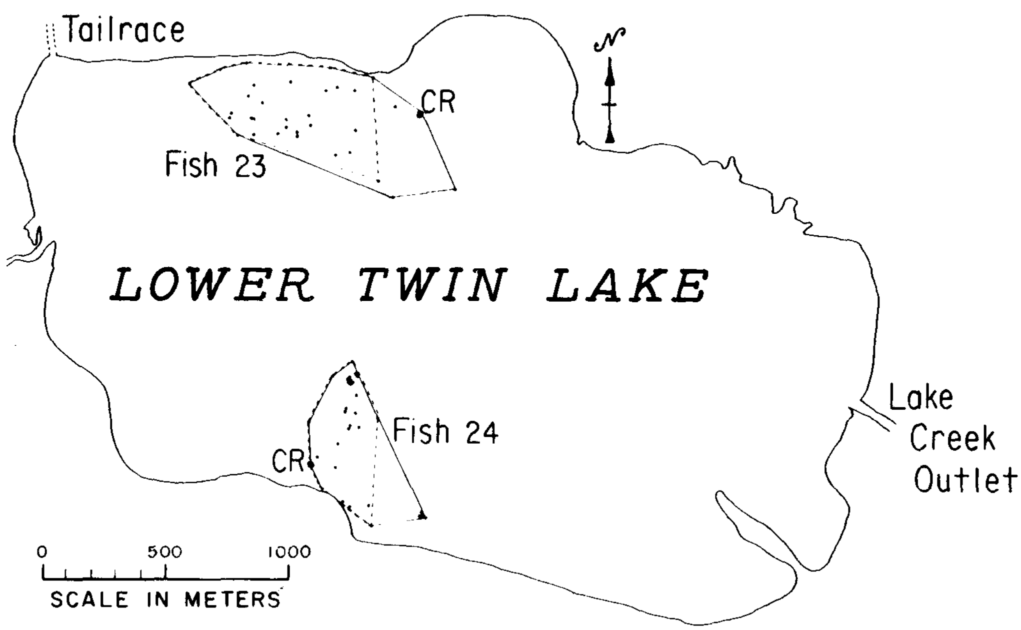

Figure F-10.—Sighting locations and cumulative and utilized home ranges (shown by dots, solid lines, and dashed lines, respectively) of fish Nos. 23 and 24 in Twin Lakes, Colorado, during the winter 1978. C represents the capture point, while R represents the point of release.

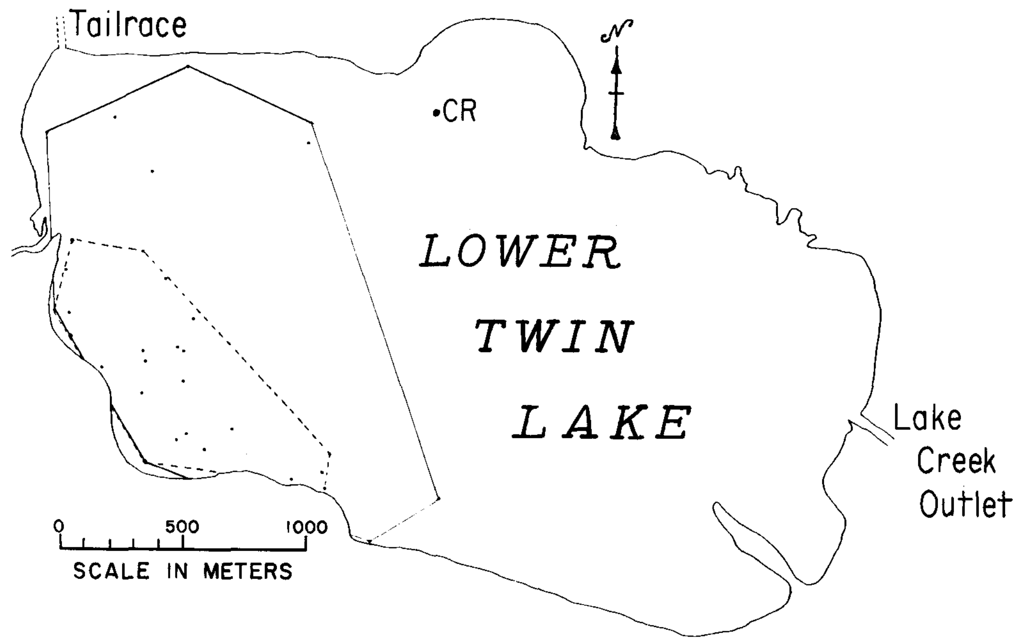

Figure F-11.—Sighting locations and cumulative and utilized home ranges (shown by dots, solid lines, and dashed lines, respectively) of fish No. 25 in Twin Lakes, Colorado, during the winter 1978. C represents the capture point, while R represents the point of release.

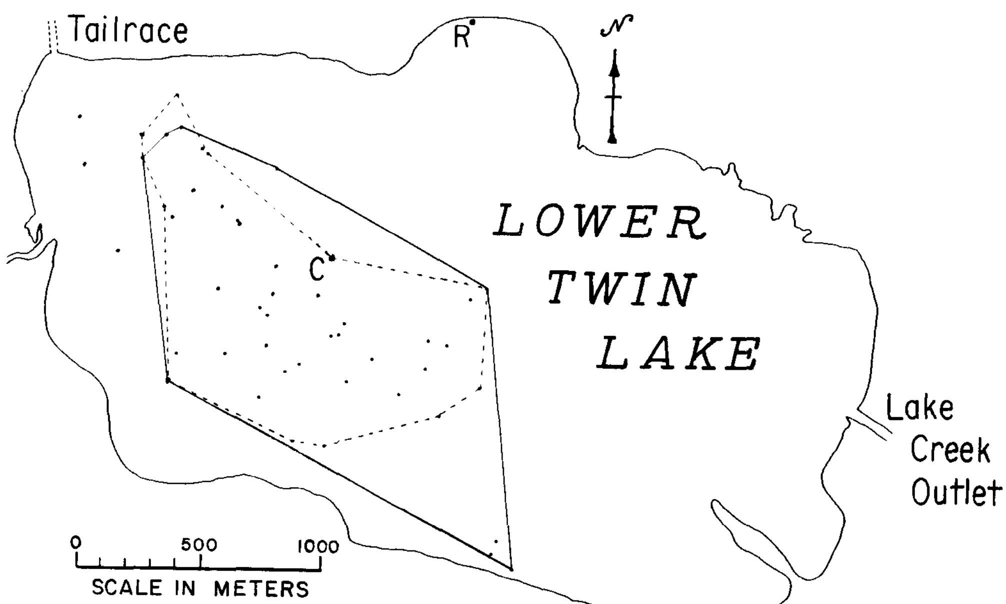

Figure F-12.—Sighting locations and cumulative and utilized home ranges (shown by dots, solid lines, and dashed lines, respectively) of fish No. 27 in Twin Lakes, Colorado, during the spring 1978. C represents the capture point, while R represents the point of release.

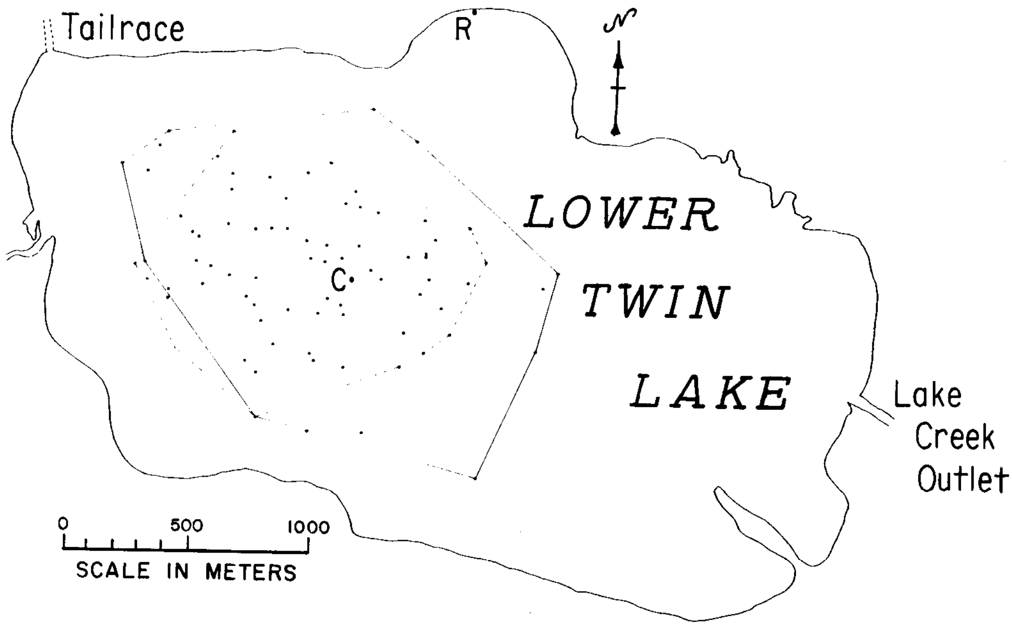

Figure F-13.—Sighting locations and cumulative and utilized home ranges (shown by dots, solid lines, and dashed lines, respectively) of fish No. 28 in Twin Lakes, Colorado, during the spring 1978. C represents the capture point, while R represents the point of release.

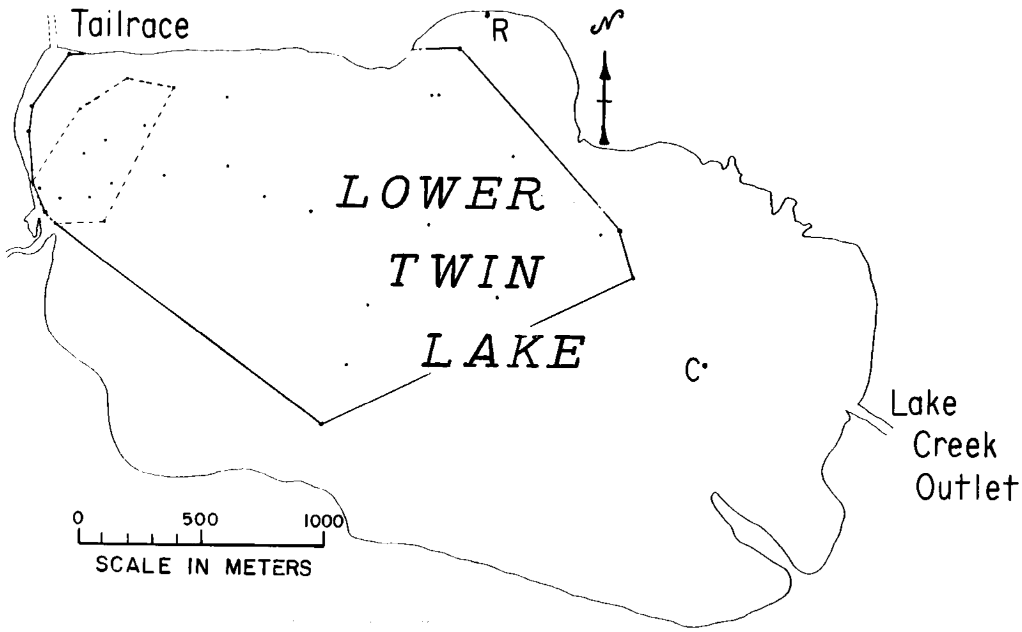

Figure F-14.—Sighting locations and cumulative and utilized home ranges (shown by dots, solid lines, and dashed lines, respectively) of fish No. 29 in Twin Lakes, Colorado, during the spring 1978. C represents the capture point, while R represents the point of release.

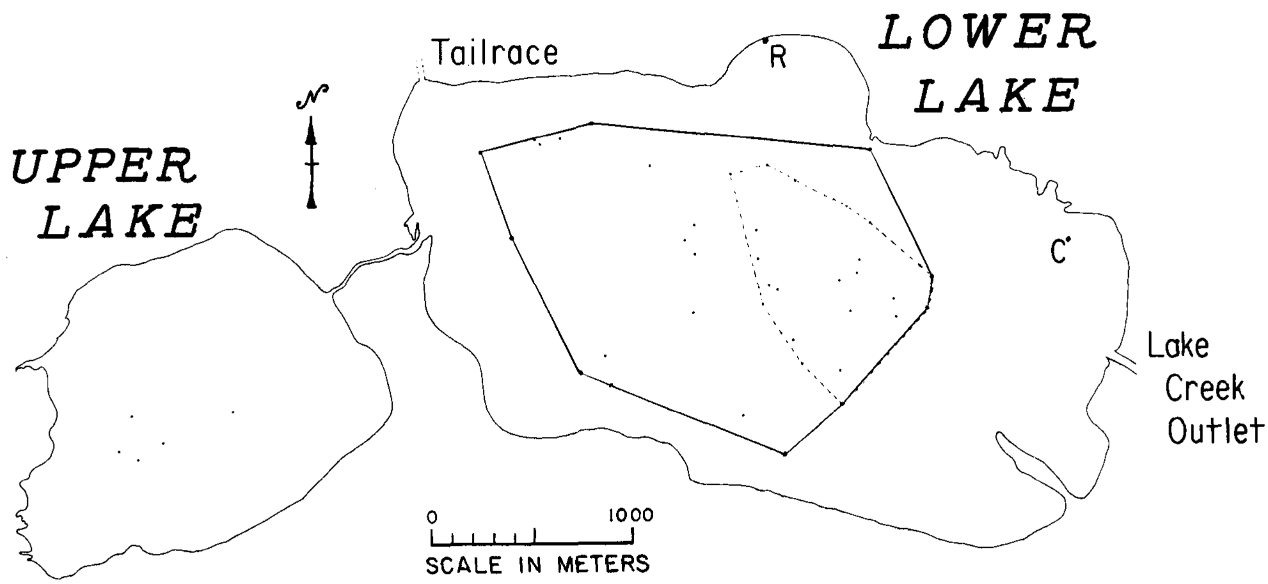

Figure F-15.—Sighting locations and cumulative and utilized home ranges (shown by dots, solid lines, and dashed lines, respectively) of fish No. 30 in Twin Lakes, Colorado, during the spring 1978. C represents the capture point, while R represents the point of release.

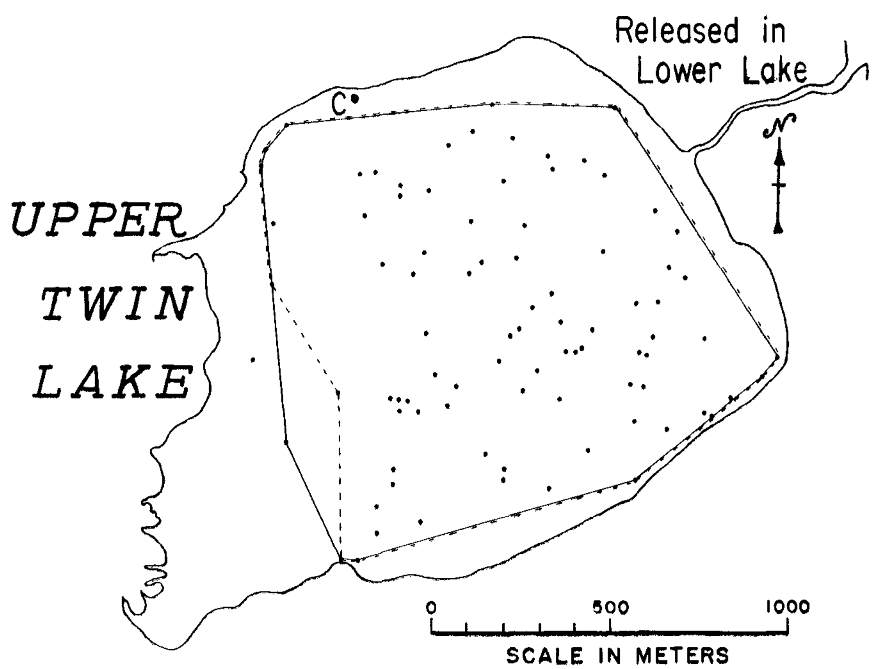

Figure F-16.—Sighting locations and cumulative and utilized home ranges (shown by dots, solid lines, and dashed lines respectively) of fish No. 31 in Twin Lakes, Colorado, during the summer 1978. C represents the point of capture. This fish was released in the lower lake.

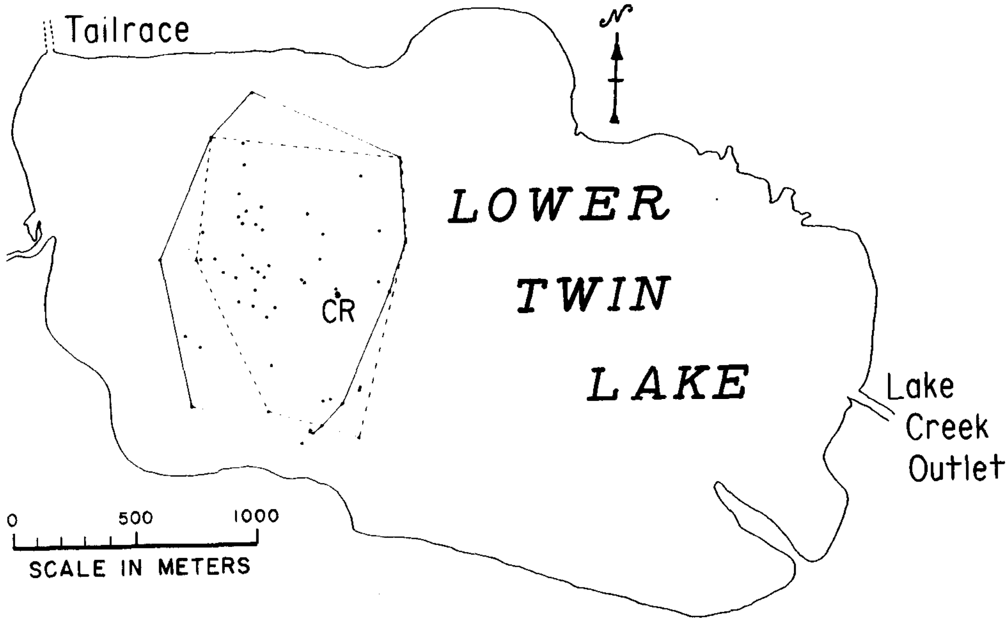

Figure F-17.—Sighting locations and cumulative and utilized home ranges (shown by dots, solid lines, and dashed lines, respectively) of fish No. 32 in Twin Lakes, Colorado, during the summer 1978. C represents the point of capture, while R represents the point of release.

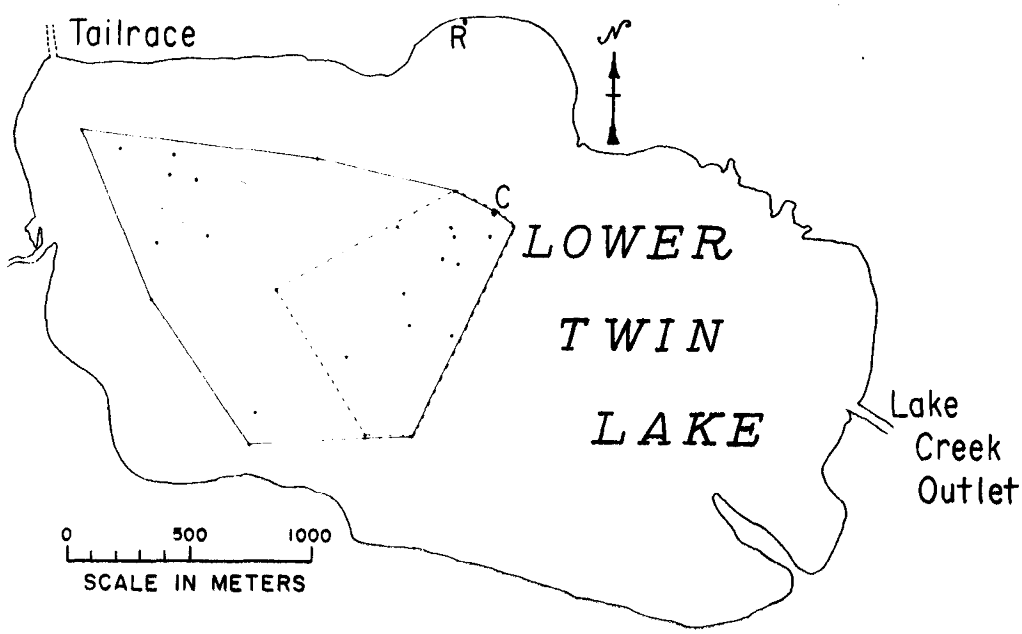

Figure F-18.—Sighting locations and cumulative and utilized home ranges (shown by dots, solid lines, and dashed lines respectively) of fish No. 33 in Twin Lakes, Colorado, during the summer 1978. C represents the point of capture, while R represents the point of release.

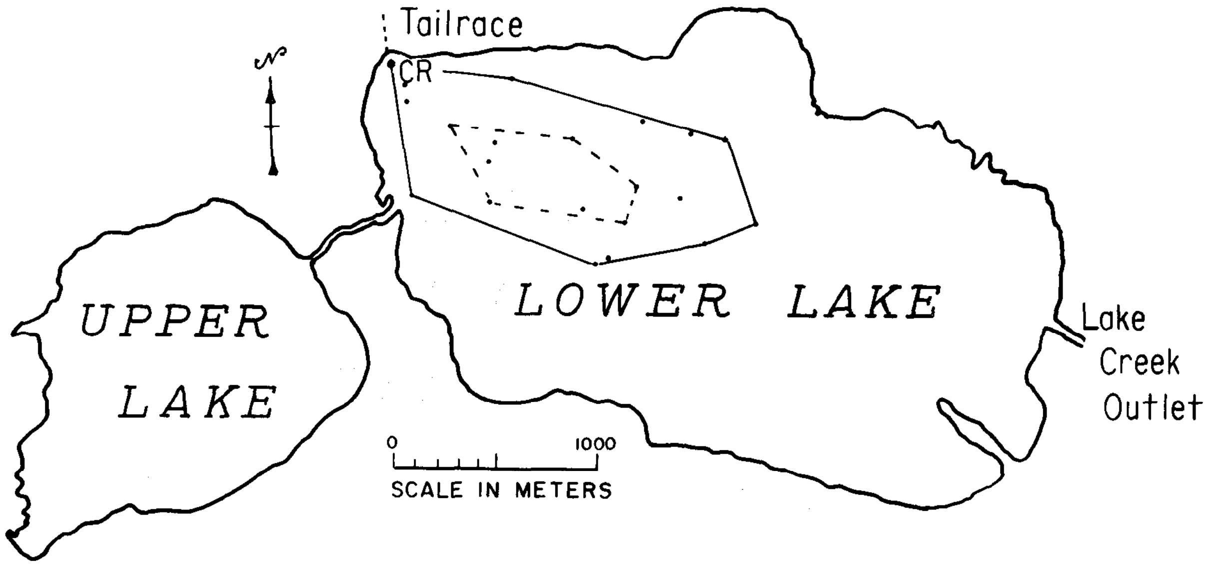

Figure F-19.—Sighting locations and cumulative and utilized home ranges (shown by dots, solid lines, and dashed lines, respectively) of fish No. 34 in Twin Lakes, Colorado, during the summer 1978. C represents the point of capture, while R represents the point of release.

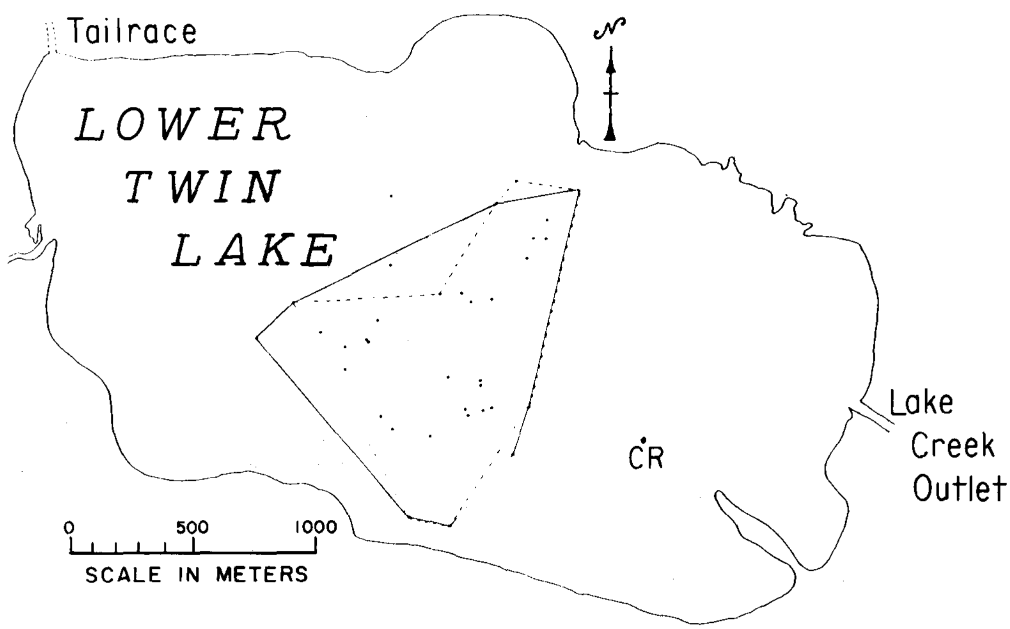

Figure F-20.—Sighting locations and cumulative and utilized home ranges (shown by dots, solid lines, and dashed lines, respectively) of fish No. 35 in Twin Lakes, Colorado, during the summer 1978. C represents the point of capture, while R represents the point of release.

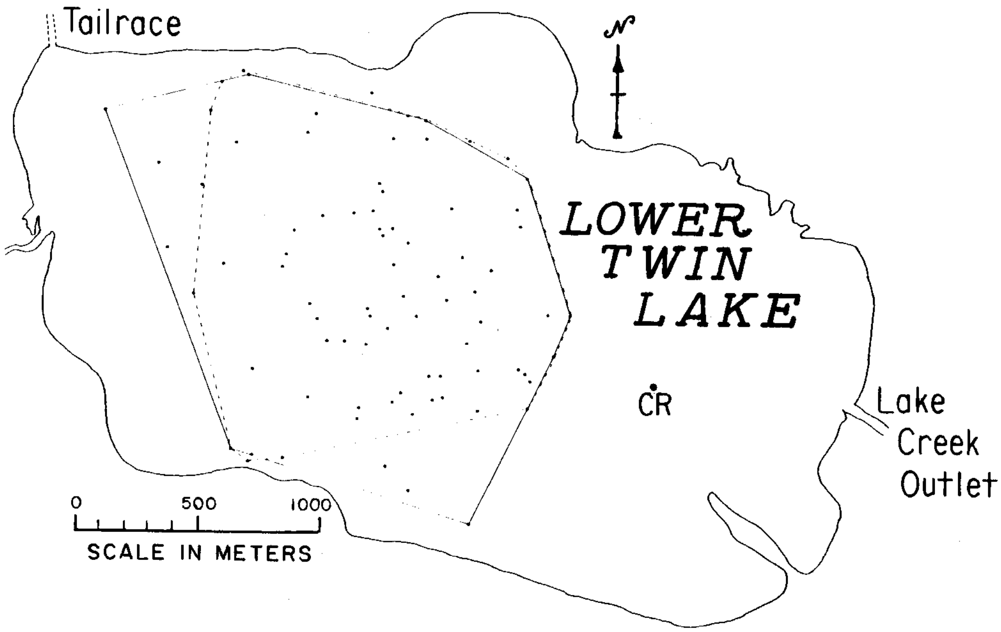

Figure F-21.—Sighting locations and cumulative and utilized home ranges (shown by dots, solid lines, and dashed lines, respectively) of fish No. 36 in Twin Lakes, Colorado, during the summer 1978. C represents the point of capture, while R represents the point of release.

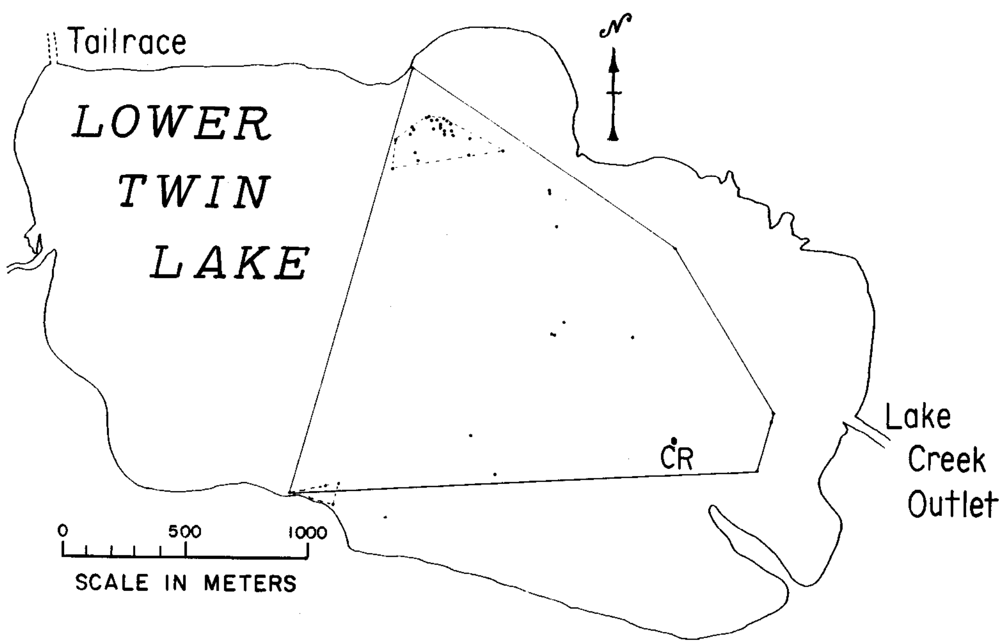

Figure F-22.—Sighting locations and cumulative and utilized home ranges (shown by dots, solid lines, and dashed lines, respectively) of fish No. 36 in Twin Lakes, Colorado, during the fall 1978. C represents the point of capture, while R represents the point of release.

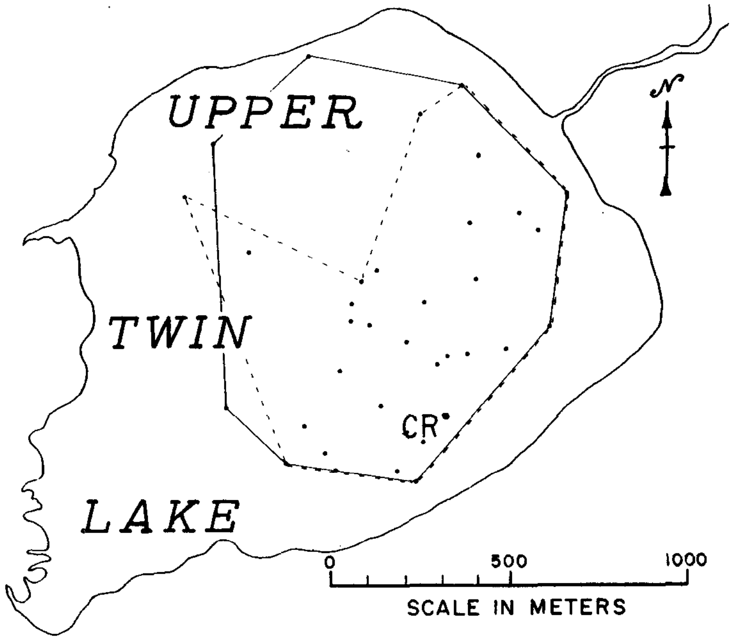

Figure F-23.—Sighting locations and cumulative and utilized home ranges (shown by dots, solid lines, and dashed lines, respectively) of fish No. 38 in Twin Lakes, Colorado, during the summer 1978. C represents the point of capture, while R represents the point of release.

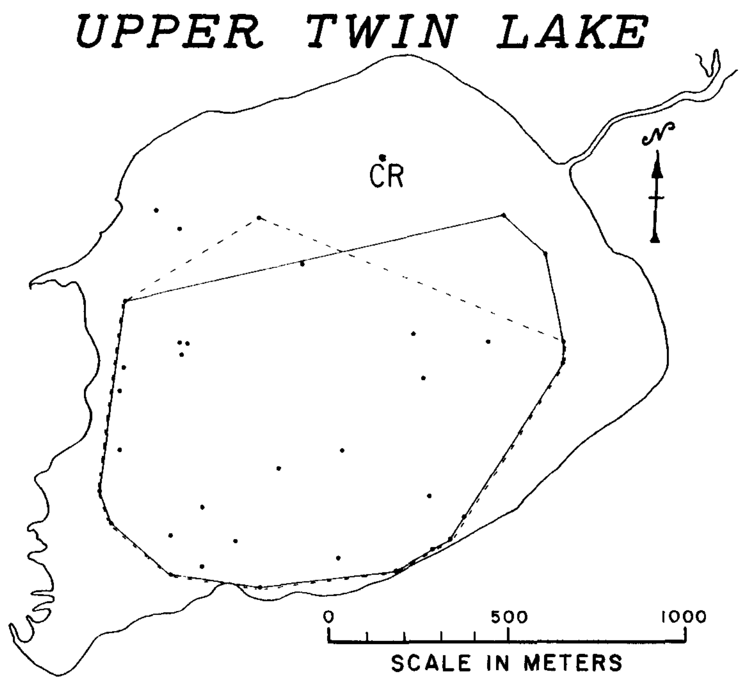

Figure F-24.—Sighting locations and cumulative and utilized home ranges (shown by dots, solid lines, and dashed lines, respectively) of fish No. 39 in Twin Lakes, Colorado, during the fall 1978. C represents the point of capture, while R represents the point of release.

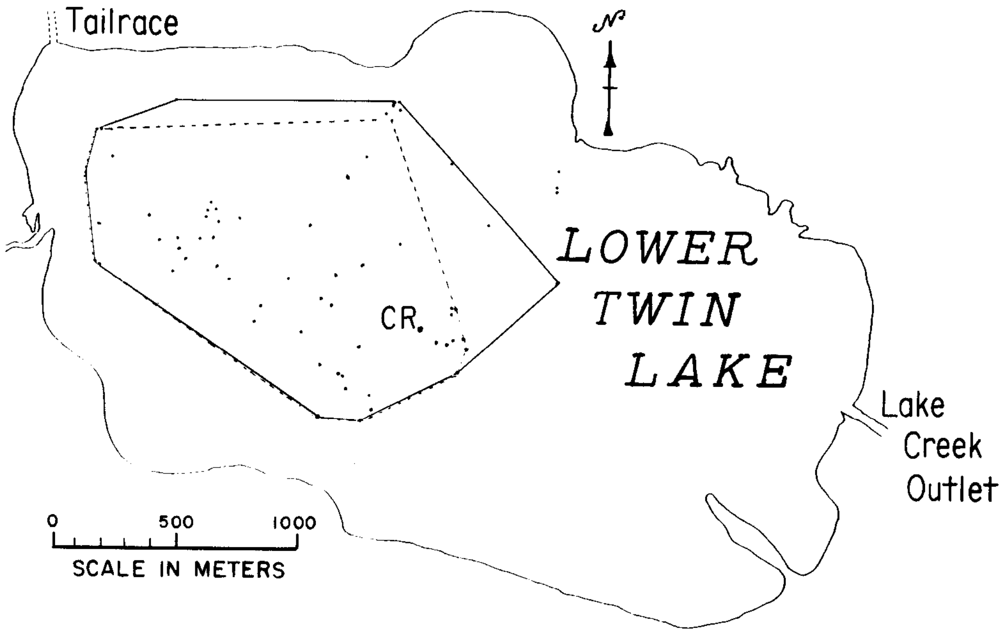

Figure F-25.—Sighting locations and cumulative and utilized home ranges (shown by dots, solid lines, and dashed lines, respectively) of fish No. 41 in Twin Lakes, Colorado, during the summer 1978. C represents the point of capture, while R represents the point of release.

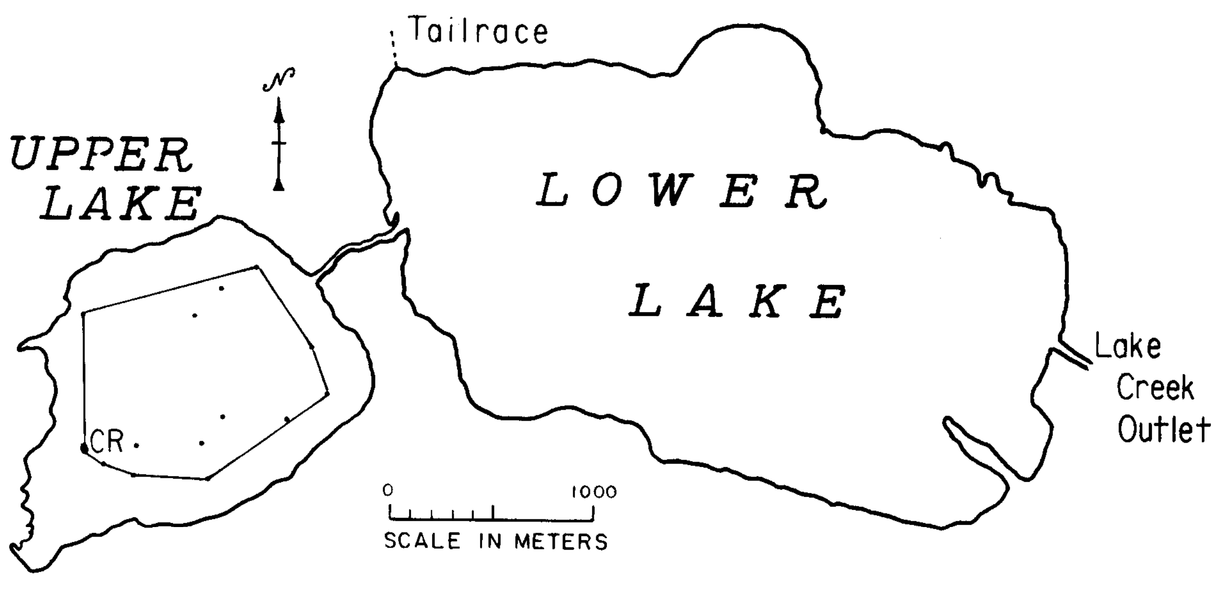

Figure F-26.—Sighting locations and maximum home range (shown by dots and lines, respectively) of fish No. 42 in Twin Lakes, Colorado, during the fall 1978. C represents the point of capture, while R represents the point of release.

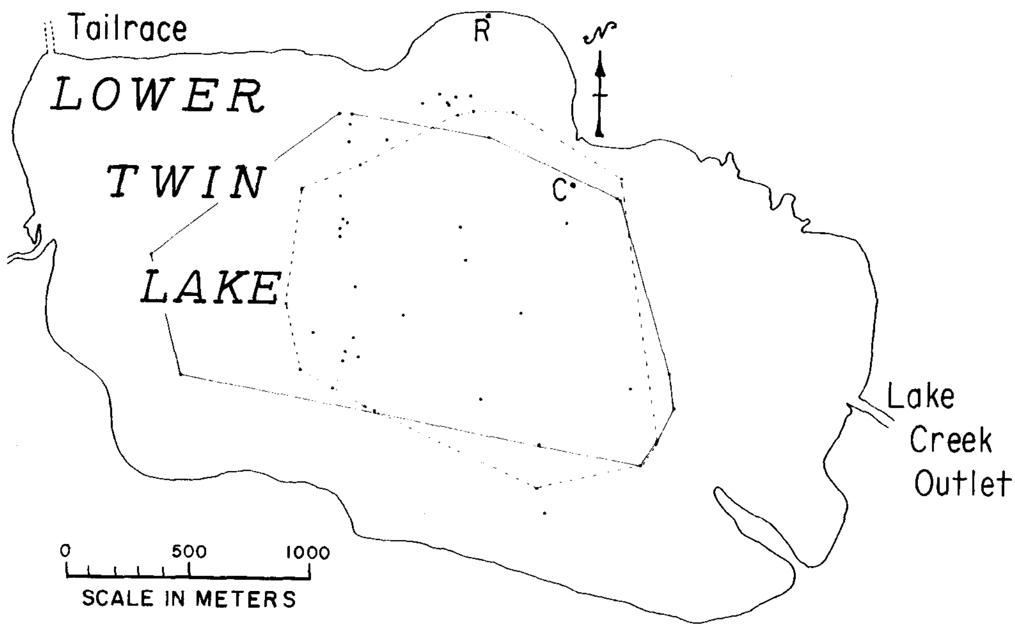

Figure F-27.—Sighting locations and cumulative and utilized home ranges (shown by dots, solid lines, and dashed lines, respectively) of fish No. 43 in Twin Lakes, Colorado, during the fall 1978. C represents the point of capture, while R represents the point of r..ease.

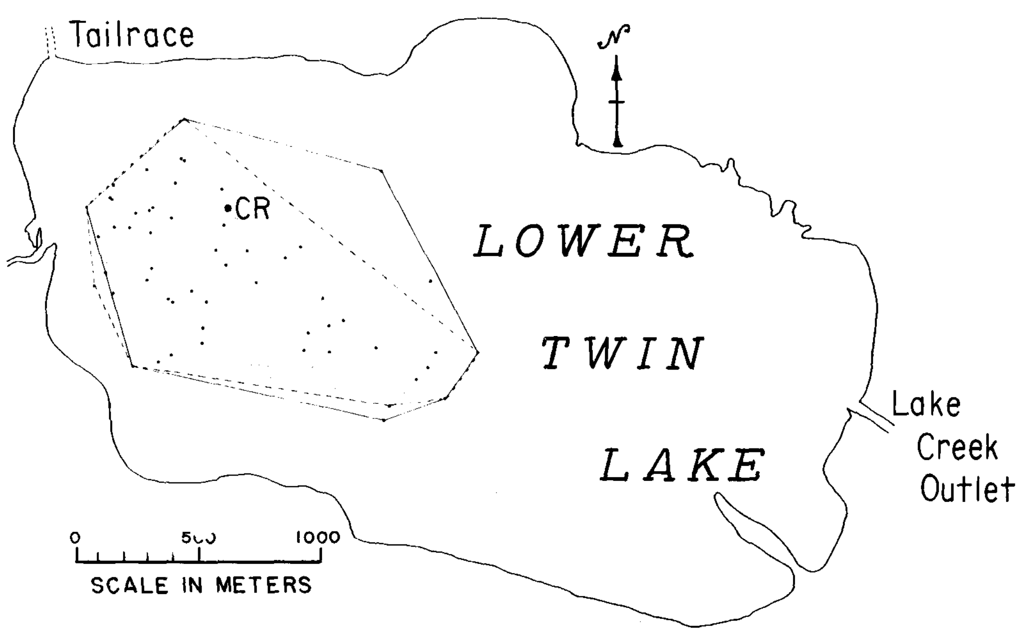

Figure F-28.—Sighting locations and cumulative and utilized home ranges (shown by dots, solid lines, and dashed lines, respectively) of fish No. 44 in Twin Lakes, Colorado, during the fall 1978. C represents the point of capture, while R represents the point of release.

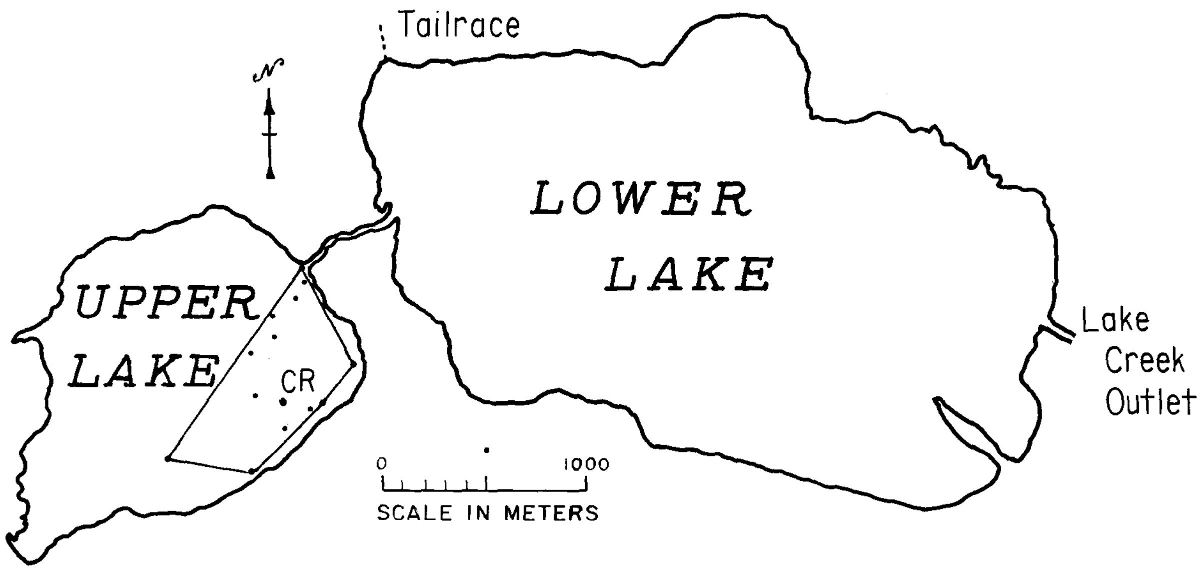

Figure F-29.—Sighting locations and maximum home range (shown by dots and lines, respectively) of fish No. 45 in Twin Lakes, Colorado, during the fall 1978. C represents the point of capture, while R represents the point of release.

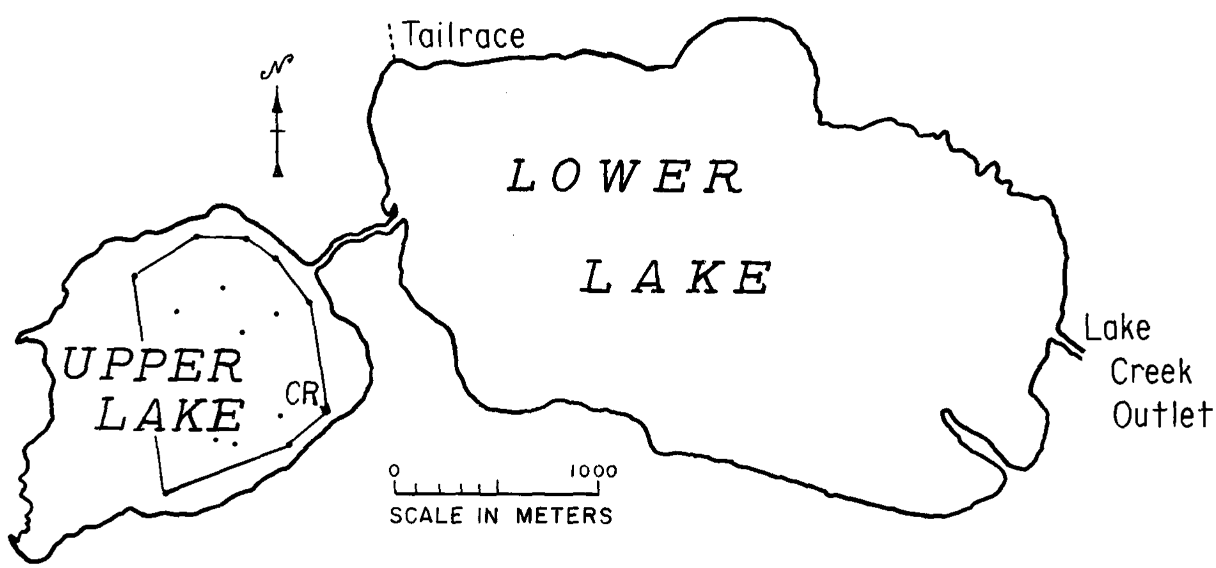

Figure F-30.—Sighting locations and maximum home range (shown by dots and lines, respectively) of fish No. 46 in Twin Lakes, Colorado, during the fall 1978. C represents the point of capture, while R represents the point of release.

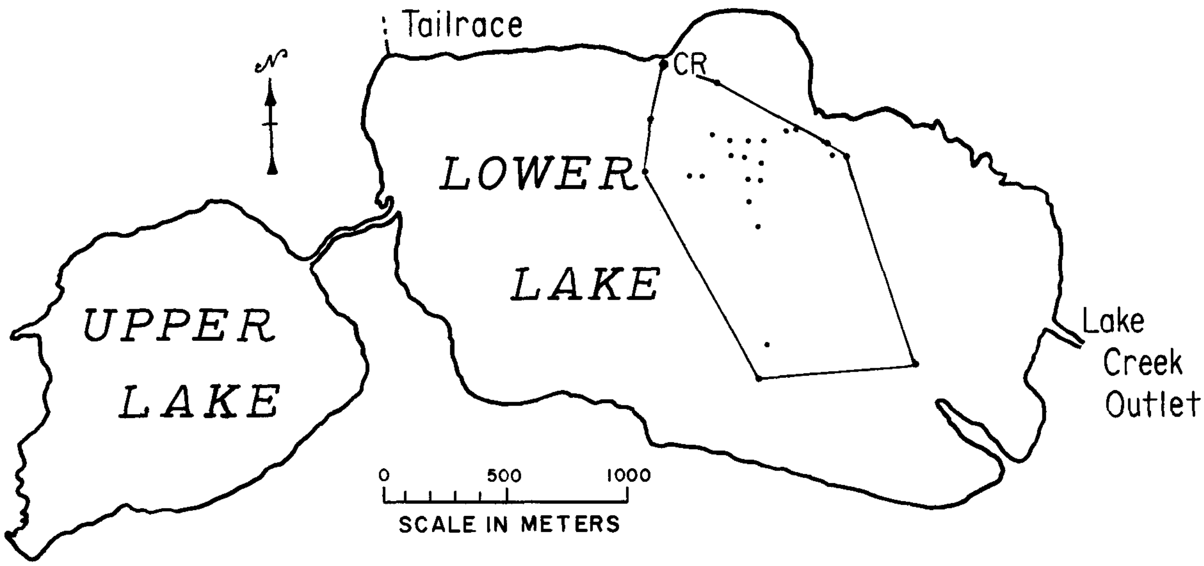

Figure F-31.—Sighting locations and maximum home range (shown by dots and lines, respectively) of fish No. 47 in Twin Lakes, Colorado, during the fall 1978. C represents the point of capture, while R represents the point of release.

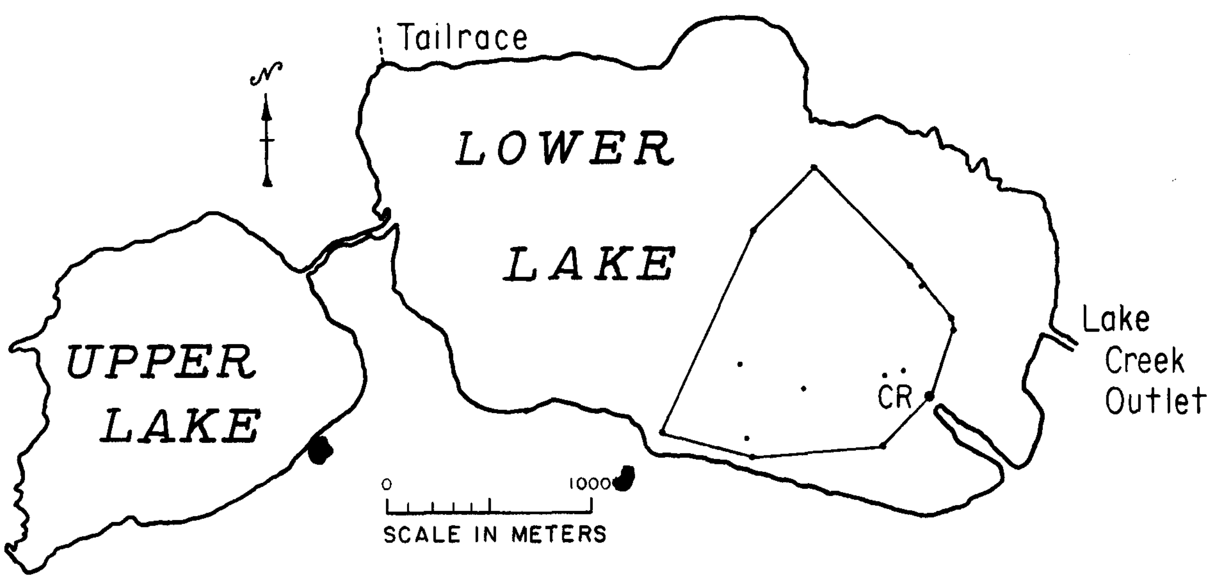

Figure F-32.—Sighting locations and maximum home range (shown by dots and lines, respectively) of fish No. 48 in Twin Lakes, Colorado, during the fall 1978. C represents the point of capture, while R represents the point of release.

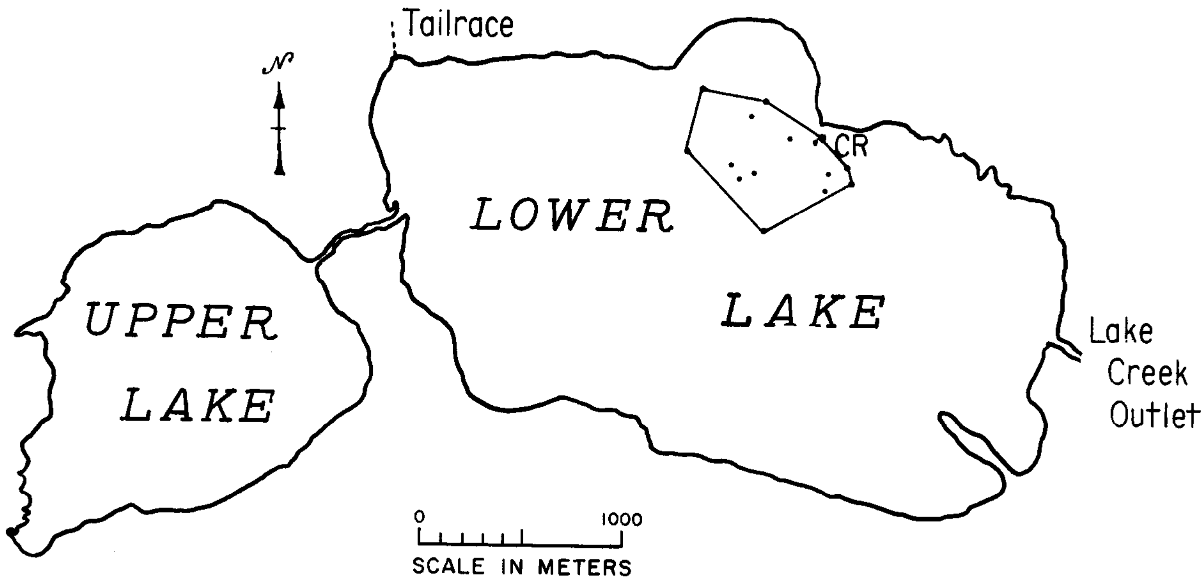

Figure F-33.—Sighting locations and maximum home range (shown by dots and lines, respectively) of fish No. 49 in Twin Lakes, Colorado, during the fall 1978. C represents the point of capture, while R represents the point of release.

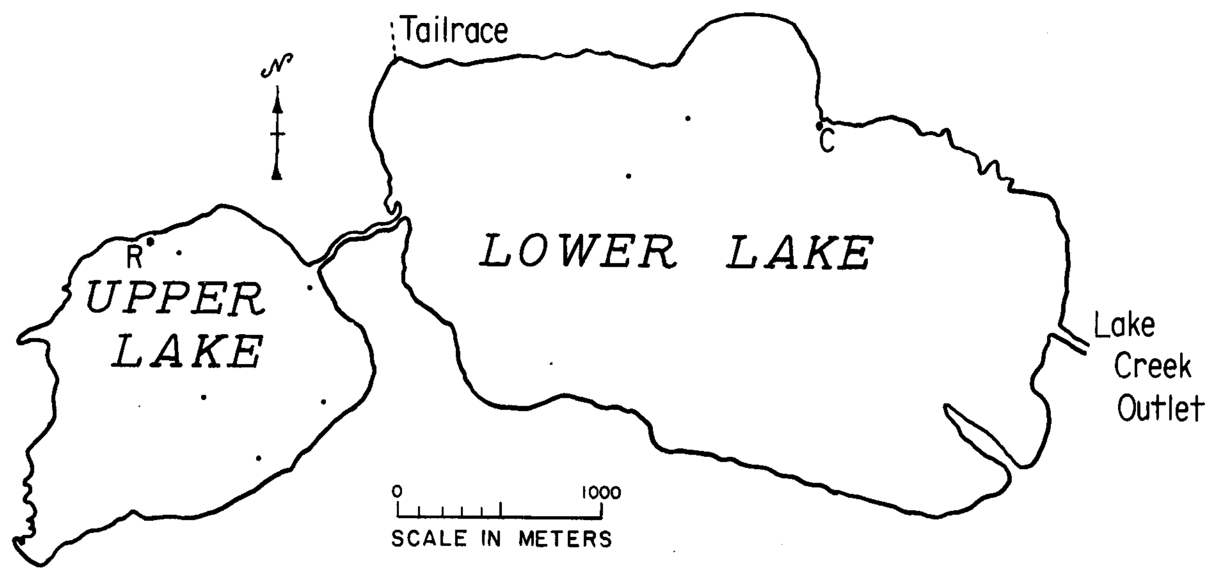

Figure F-34.—Sighting locations (shown by dots) of fish No. 50 in Twin Lakes, Colorado, during the fall 1978. C represents the point of capture, while R represents the point of release.

APPENDIX G

STATISTICAL ANALYSIS OF HOME RANGE DATA FROM LAKE TROUT, TWIN LAKES, COLORADO, BETWEEN JULY 1977 AND NOVEMBER 1978

Table G-1.—*One-way analysis of variance of cumulative home range sizes from lake trout in Twin Lakes, Colorado, which were tracked during 1977 and 1978*

Source of Variation	Sum of Squares	DF	Mean Squares	F	Significance of F
Between seasons	51,193.68	3	17,064.56	5.09	0.01
Within seasons	20,414.07	24	3,350.59		
Total	131,607.75	27			

Table G-2.—*One-way analysis of variance of utilized home range sizes from lake trout in Twin Lakes, Colorado, which were tracked during 1977 and 1978*

Source of Variation	Sum of Squares	DF	Mean Squares	F	Significance of F
Between seasons	20,284.19	3	6,761.40	4.24	0.02
Within seasons	36,706.43	23	1,595.93		
Total	56,990.63	26			

APPENDIX H

STATISTICAL ANALYSIS OF LAKE TROUT GILL NETTING DATA FROM TWIN LAKES, COLORADO, DURING 1978

Table H-1.—*Two-way analysis of variance of gill netting data from stations 1-10 in Twin Lakes, Colorado*

Source of Variation	Sum of Squares	DF	Mean Squares	F	Significance of F
Main Effects	3.221	12	0.268	7.908	0.001
Stations	1.335	9	0.148	4.371	0.001
Seasons	1.908	3	0.636	18.737	0.001
Two Way Interactions	1.718	27	0.064	1.875	0.016
Explained	4.939	39	0.127	3.732	0.001
Residual	2.783	82	0.034		
Total	7.722	121	0.064		

Table H-2.—*One-way analysis of variance of gill netting data from stations one through 10 in Twin Lakes, Colorado, during the spring 1978*

Source of Variation	Sum of Squares	DF	Mean Squares	F	Significance of F
Between stations	1.1960	9	0.1329	2.22	0.1060
Within stations	0.6574	11	0.0598		
Total	1.8533	20			

Station	Count	Mean	Standard Deviation	95% Conf. Int. for Mean
1	3	0.2403	0.1384	-0.1035 to 0.5842
2	2	0.2900	0.1556	-1.1077 to 1.7877
3	2	0.5105	0.1775	-1.0841 to 2.1051
4	2	0.5995	0.4575	-3.5110 to 4.7100
5	2	0.4675	0.4264	-3.3634 to 4.2984
6	4	0.8183	0.1108	0.6419 to 0.9946
7	1	0.3640	0	0.3640 to 0.3640
8	2	0.0435	0.0615	-0.5092 to 0.5962
9	1	0.1660	0	0.1660 to 0.1660
10	2	0.4105	0.3627	-2.8486 to 3.6696
Total	21	0.4365	0.3044	0.2980 to 0.5751

Table H-3.—*One-way analysis of variance of gill netting data from stations one through 10 in Twin Lakes, Colorado, during the fall 1978*

Source of Variation	Sum of Squares	DF	Mean Squares	F	Significance of F
Between stations	0.7327	9	0.0814	1.291	0.2869
Within stations	1.7031	27	0.0631		
Total	2.4358	36			

Station	Count	Mean	Standard Deviation	95% Conf. Int. for Mean
1	5	0.2534	0.2061	-0.0025 to 0.5093
2	4	0.4635	0.3598	-0.1090 to 1.0360
3	2	0.1110	0.1570	-1.2994 to 1.5214
4	6	0.3102	0.0724	0.2341 to 0.3862
5	2	0.2790	0.2107	-1.6142 to 2.1722
7	3	0.1940	0.1681	-0.2235 to 0.6115
7	10	0.4907	0.3045	0.2729 to 0.7085
8	2	0.2500	0.3536	-2.9265 to 3.4265
9	1	0	0	0 to 0
10	2	0.5590	0.1838	-1.0928 to 2.2108
Total	37	0.3478	0.2601	0.2611 to 0.4345

Table H-4.—*One-way analysis of variance of gill netting data from stations one through 10 in Twin Lakes, Colorado, during the winter 1978*

Source of Variation	Sum of Squares	DF	Mean Squares	F	Significance of F
Between stations	0.3027	9	0.0336	2.98	0.0274
Within stations	0.1807	16	0.0113		
Total	0.4834	25			

Station	Count	Mean	Standard Deviation	95% Conf. Int. for Mean
1	2	0.0105	0.0148	-0.1229 to 0.1439
2	5	0.3262	0.1905	0.0897 to 0.5627
3	1	0.0430	0	0.0430 to 0.0430
4	3	0.0140	0.0242	-0.0462 to 0.0742
5	1	0	0	0 to 0
6	5	0.1280	0.0693	0.0420 to 0.2140
7	4	0.1753	0.0477	0.0993 to 0.2512
8	k	0.0430	0	0.0430 to 0.0430
9	2	0.0965	0.0120	-0.0115 to 0.2045
10	2	0.1530	0.0891	-0.6475 to 0.9535
Total	26	0.1392	0.1391	0.0831 to 0.1954

Table H-5.—*One-way analysis of variance of gill netting data from stations one through 10 in Twin Lakes, Colorado, during the summer 1978*

Source of Variation	Sum of Squares	DF	Mean Squares	F	Significance of F
Between stations	0.8219	9	0.0913	10.58	
Within stations	0.2417	28	0.0086		
Total	1.0636	37			

Station	Count	Mean	Standard Deviation	95% Conf. Int. for Mean
1	5	0.0154	0.0344	-0.0274 to 0.0582
2	3	0.1527	0.1605	-0.2461 to 0.5514
3	4	0.1568	0.1174	-0.0300 to 0.3435
4	3	0.0247	0.0427	-0.0815 to 0.1308
5	3	0.1367	0.1196	-0.1604 to 0.4337
6	5	0.4880	0.1175	0.3421 to 0.6339
7	4	0.0727	0.0605	-0.0235 to 0.1690
8	2	0.1110	0.1570	-1.2994 to 1.5214
9	5	0.0154	0.0344	-0.0274 to 0.0582
10	4	0.1350	0.0736	0.0178 to 0.2522
Total	38	0.1373	0.1695	0.0815 to 0.1930

APPENDIX I

DATA CONCERNING THE SELECTION OF TEMPERATURE, DEPTH, AND DISTANCE OFF THE BOTTOM FOR LAKE TROUT IN TWIN LAKES, COLORADO, TAGGED WITH TEMPERATURE-SENSITIVE TRANSMITTERS, DURING 1978

Table I-1.—*Data from lake trout in Twin Lakes, Colorado, tagged with temperature-sensitive transmitters, during 1978*

Fish No.	Date	Time	Depth (m)	Temp. (°C)	Bottom Depth (m)	Distance off bottom (m)
32	7/17	0600	3.5	14.8	19.8	16.3
		0905	3.5	14.8	21.3	17.8
	7/24	1000	11.0	11.2	19.8	7.8
	7/26	0850	10.0	12.6	16.8	6.8
		1110	10.0	12.6	16.8	6.8
		1355	10.0	12.6	16.8	6.8
		1630	11.5	11.2	18.2	6.8
		2030	10.5	12.0	19.8	9.3
		2245	10.5	12.0	19.8	9.3
	7/27	0215	10.5	12.0	19.8	9.3
		0555	11.5	11.2	18.3	6.8
		0800	7.0	14.0	18.6	11.6
	7/30	1000	13.5	10.5	21.3	7.8
		1300	13.5	10.5	24.4	10.9
	8/7	0925	23.0	9.5	26.3	3.3
		1205	23.0	9.5	24.7	1.7
		1505	23.0	9.5	23.2	.2
		1835	23.0	9.5	24.7	1.7
		2030	23.0	9.5	23.2	.2
		2345	23.0	9.5	23.2	.2
	8/8	0340	23.0	9.5	24.7	1.7
		0620	23.0	9.5	24.7	1.7
	8/9	1010	16.0	10.0	19.8	3.8
		1305	16.0	10.0	19.8	3.8
	8/14	0950	23.0	9.5	23.5	.5
		1215	23.0	9.5	23.5	.5
		1515	23.0	9.5	23.5	.5
		1800	23.0	9.5	23.5	.5
	8/15	0650	23.0	9.5	23.5	.5
		0955	23.0	9.5	23.5	.5
		1140	23.0	9.5	23.5	.5
		1500	23.0	9.5	23.5	.5
		1845	23.0	9.5	23.5	.5
		2155	23.0	9.5	23.5	.5
	8/16	0100	23.0	9.5	23.5	.5
		0455	23.0	9.5	23.5	.5
		0815	23.0	9.5	23.5	.5
	8/21	1105	23.0	9.5	23.5	.5
		1430	23.0	9.5	23.5	.5
		1750	23.0	9.5	23.5	.5
		2115	23.0	9.5	23.5	.5

Table I-1.—*Data from lake trout in Twin Lakes, Colorado, tagged with temperature-sensitive transmitters, during 1978.*—Continued

Fish No.	Date	Time	Depth (m)	Temp. (°C)	Bottom Depth (m)	Distance off bottom (m)
32	8/22	0110	23.0	9.5	23.5	.5
		0415	23.0	9.5	23.5	.5
		0640	23.0	9.5	23.5	.5
		0930	23.0	9.5	23.5	.5
		1150	23.0	9.5	23.5	.5
33	8/7	0630	23.5	9.5	24.4	.9
		0915	23.5	9.5	24.4	.9
		1210	23.5	9.5	24.4	.9
		1520	23.5	9.5	24.4	.9
		1800	23.5	9.5	24.4	.9
		2045	23.5	9.5	24.4	.9
		2355	23.5	9.5	24.4	.9
	8/8	0320	23.5	9.5	24.4	.9
		0550	23.5	9.5	24.4	.9
	8/14	0900	23.0	9.5	23.5	.5
		1400	23.0	9.5	23.5	.5
		1930	23.0	9.5	23.5	.5
	8/15	0635	23.0	9.5	23.5	.5
		0920	23.0	9.5	23.5	.5
		1200	23.0	9.5	23.5	.5
		1450	23.0	9.5	23.5	.5
		1850	23.0	9.5	23.5	.5
	8/21	1020	23.0	9.5	23.5	.5
		1700	23.0	9.5	23.5	.5
		2055	23.0	9.5	23.5	.5
	8/22	0030	23.0	9.5	23.5	.5
		0340	23.0	9.5	23.5	.5
		0555	23.0	9.5	23.5	.5
		1130	23.0	9.5	23.5	.5
		1605	23.0	9.5	23.5	.5
	9/4	1750	22.5	9.5	23.5	1.0
	9/5	1550	22.5	9.5	23.5	1.0
35	8/7	0745	11.0	11.8	21.3	10.3
		0940	7.0	14.7	21.3	14.3
		1150	11.0	11.8	21.3	10.3
		1450	11.0	11.8	21.3	10.3
		1815	11.0	11.8	21.3	10.3
		2000	8.0	13.2	19.8	11.3
		2335	9.0	12.5	19.8	10.8
	8/8	0300	9.0	12.5	19.8	10.8
		0600	8.0	13.2	19.8	8.8
	8/9	1000	5.0	15.4	18.3	13.3
	8/14	0925	11.5	11.8	22.9	11.4
		1200	11.5	11.8	21.3	9.4
		1510	11.5	11.8	21.3	9.8
		1820	11.5	11.8	21.3	9.8
	8/15	0645	11.5	11.8	22.9	11.4
		0940	11.5	11.8	22.9	11.4
		1150	11.5	11.8	22.9	11.4
		1505	11.5	11.8	22.9	11.4
		1855	11.5	11.8	21.3	9.8
		2135	11.5	11.8	21.3	9.8

Table I-1.—*Data from lake trout in Twin Lakes, Colorado, tagged with temperature-sensitive transmitters, during 1978.*—Continued

Fish No.	Date	Time	Depth (m)	Temp. (°C)	Bottom Depth (m)	Distance off bottom (m)
35	8/16	0040	11.5	11.8	18.3	6.8
		0430	11.5	11.8	22.9	11.4
		0805	11.5	12.5	22.9	11.4
	8/21	1135	8.8	13.2	21.3	12.5
		1440	2.0	14.4	16.8	14.8
		1755	11.2	11.8	21.3	10.1
		2100	11.2	11.8	21.3	10.1
	8/22	0100	11.2	11.8	21.3	10.1
		0405	11.2	11.8	21.3	10.1
		0645	11.2	11.8	22.9	11.7
		0920	10.5	12.5	16.8	6.3
		1145	10.5	13.9	13.7	3.2
		1430	10.5	14.7	10.7	.2
		1600	10.5	11.8	21.3	10.3
38	8/28	1450	16.0	6.6	17.0	1.0
	8/29	0900	16.0	6.6	18.0	2.0
		1055	16.0	6.6	16.0	0.0
		1140	11.5	9.0	16.8	5.3
		1520	11.5	9.0	16.8	5.3
	8/30	0845	16.5	6.6	16.8	10.3
	9/2	1830	16.5	6.6	17.0	.5
	9/3	0925	5.0	6.6	6.0	1.0
		1100	16.5	6.6	17.0	.5
	9/4	1815	17.0	6.6	19.0	2.0
	9/5	1000	17.0	6.6	22.0	5.0
		1200	17.0	6.6	22.0	5.0
		1530	17.0	6.6	22.0	5.0
		1830	17.0	6.6	20.0	3.0
	9/6	0700	17.0	6.6	19.0	2.0
		1015	17.0	6.6	20.0	3.0
	9/7	1930	17.0	6.6	22.0	5.0
	9/8	0800	17.0	6.6	18.0	1.0
	9/11	1435	17.0	6.6	19.0	2.0
	9/13	0715	17.0	6.6	17.0	0.0
		0940	17.0	9.0	22.0	5.0
	9/20	1000	1.0	14.5	3.0	2.0
		1145	13.5	8.0	19.0	5.5
		1540	10.0	10.0	22.0	12.0
		1725	10.0	10.0	12.0	2.0
	9/21	0700	10.0	10.0	18.0	8.0
	9/25	0935	18.0	7.0	18.5	.5
		1205	1810	7.0	18.5	.5
	9/26	0940	18.0	7.0	18.5	.5
		1555	18.0	7.0	18.5	.5
		1910	18.0	7.0	18.0	.1
	9/27	0735	6.0	10.0	6.0	.1
	9/28	1250	10.0	10.0	13.0	3.0
41	9/5	1230	20.0	9.6	22.8	2.8
		1500	20.0	9.6	22.8	2.8
		1800	20.0	9.6	22.8	2.8

Table I-1.—*Data from lake trout in Twin Lakes, Colorado, tagged with temperature-sensitive transmitters, during 1978.*—Continued

Fish No.	Date	Time	Depth (m)	Temp. (°C)	Bottom Depth (m)	Distance off bottom (m)
41	9/6	0635	20.0	9.6	22.8	2.8
		0945	14.0	10.5	15.0	1.0
	9/8	0830	20.0	9.6	20.5	.5
	9/11	1420	20.0	9.6	21.3	1.3
	9/12	1940	20.0	9.6	20.5	.5
	9/13	0030	20.0	9.6	21.3	1.3
		0345	20.0	9.6	21.3	1.3
		0650	20.0	9.6	21.3	1.3
	9/17	0940	20.0	9.6	21.3	1.3
	9/20	0915	21.0	9.6	21.3	.3
		1230	21.0	9.6	21.3	.3
		1510	21.0	9.6	21.3	.3
		1755	21.0	9.6	21.3	.3
		2115	21.0	9.6	21.3	.3
	9/21	0115	21.0	9.6	21.3	.3
		0500	21.0	9.6	21.3	.3
	9/22	1300	21.0	9.6	21.3	.3
	9/25	0920	21.0	10.5	21.3	.3
		1155	21.0	10.5	21.3	.3
		1545	21.0	10.5	21.3	.3
	9/26	0925	21.0	10.5	21.3	.3
		1220	21.0	10.5	21.3	.3
		1530	21.0	10.5	21.3	.3
		1840	21.0	10.5	21.3	.3
		2200	21.0	10.5	21.3	.3
	9/27	0110	21.0	10.5	21.3	.3
		0415	21.0	10.5	21.3	.3
	9/28	1210	21.0	10.5	21.3	.3
	10/3	1145	*	11.0	*	*
	10/4	2140	*	11.0	*	*
	10/5	0130	*	11.0	*	*
		0450	*	11.0	*	*
		0720	*	11.0	*	*
		1115	*	11.0	*	*
		1455	*	11.0	*	*
		1705	*	11.0	*	*
		2015	*	11.0	*	*
	10/9	1040	*	11.0	*	*
	10/10	1010	*	11.0	*	*
		1225	*	11.0	*	*
		1600	*	11.0	*	*
		1955	*	11.0	*	*
		2355	*	11.0	*	*
	10/11	0330	*	11.0	*	*
		0705	*	11.0	*	*
		0940	*	11.0	*	*
	10/13	1020	*	11.0	*	*
	10/16	1120	*	10.0	*	*
		1630	*	10.0	*	*

Table I-1.—*Data from lake trout in Twin Lakes, Colorado, tagged with temperature-sensitive transmitters, during 1978.*—Continued

Fish No.	Date	Time	Depth (m)	Temp. (°C)	Bottom Depth (m)	Distance off bottom (m)
41	10/17	1055	*	10.0	*	*
		1430	*	10.0	*	*
		1655	*	10.0	*	*
		2055	*	10.0	*	*
	10/18	0055	*	10.0	*	*
		0330	*	10.0	*	*
		0600	*	10.0	*	*
	10/23	1300	*	10.0	*	*
		1515	*	10.0	*	*
		1750	*	10.0	*	*
	10/24	0815	*	10.0	*	*
46	10/13	1055	20.0	8.2	21.0	1.0
	10/16	1145	20.0	8.2	21.0	1.0
	10/17	1105	20.0	8.2	21.0	1.0
	10/18	1055	20.0	8.2	21.0	1.0
		1620	20.0	8.2	21.0	1.0
	10/23	1430	15-21	7.7	16.0	*
		1700	15-21	7.7	17.5	*
	10/24	0800	15-21	7.7	17.5	*
		1320	15-21	7.7	15.0	*
	10/25	0645	15-21	7.7	18.5	*
	10/31	0950	5-15	7.4	5.0	*
		1400	5-15	7.4	11.5	*
	11/01	1545	5-16	7.4	14.5	*
47	10/13	1030	*	11.0	*	*
	10/16	1110	*	10.0	*	*
		1620	*	10.0	*	*
	10/17	1050	*	10.0	*	*
		1405	*	10.0	*	*
		1625	*	10.0	*	*
		2025	*	10.0	*	*
	10/18	0025	*	10.0	*	*
		0620	*	10.0	*	*
		1010	*	10.0	*	*
	10/23	1350	*	8.2	*	*
		1400	*	8.2	*	*
		1540	*	8.2	*	*
		1755	*	8.2	*	*
	10/24	0755	*	8.2	*	*
		1110	*	8.2	*	*
		1355	*	8.2	*	*
		1755	*	8.2	*	*
	10/25	0115	*	8.2	*	*
		0510	*	8.2	*	*
		0855	*	8.2	*	*
		2105	*	8.2	*	*
	10/31	0900	*	8.2	*	*
		1245	*	8.2	*	*
	11/01	1500	*	8.2	*	*

*Lack of thermal stratification did not allow determination of factor.

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